HYDRAULICS OF RIVER FLOW UNDER ARCH BRIDGES

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by

J. W. DELLEUR

Joint Highway Research Project

PURDUE UNIVERSITY
LAFAYETTE INDIANA

Final Report

HYDRAULICS OF RIVER FLOW UNDER ARCH BRIDGES

Vol. II

by

J. W. Delleur
Professor of Hydraulic Engineering

Joint Highway Research Project

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or the
Bureau of Public Roads

Lafayette, Indiana

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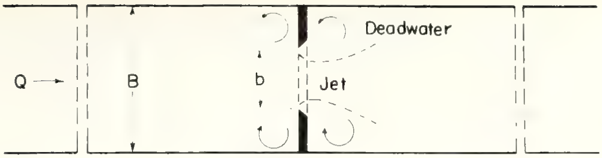
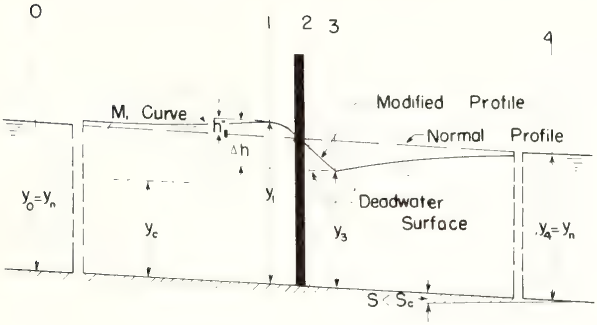


A.) PLAN



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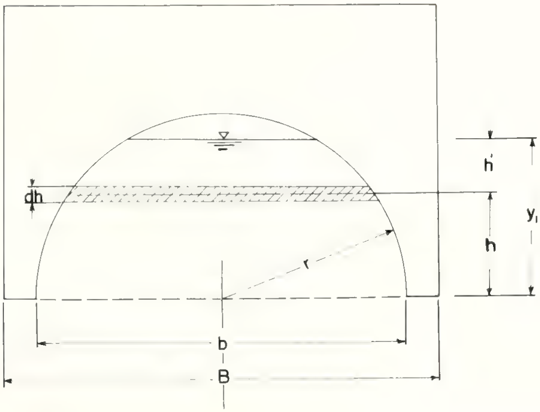


FIGURE 3-1 DEFINITION SKETCH

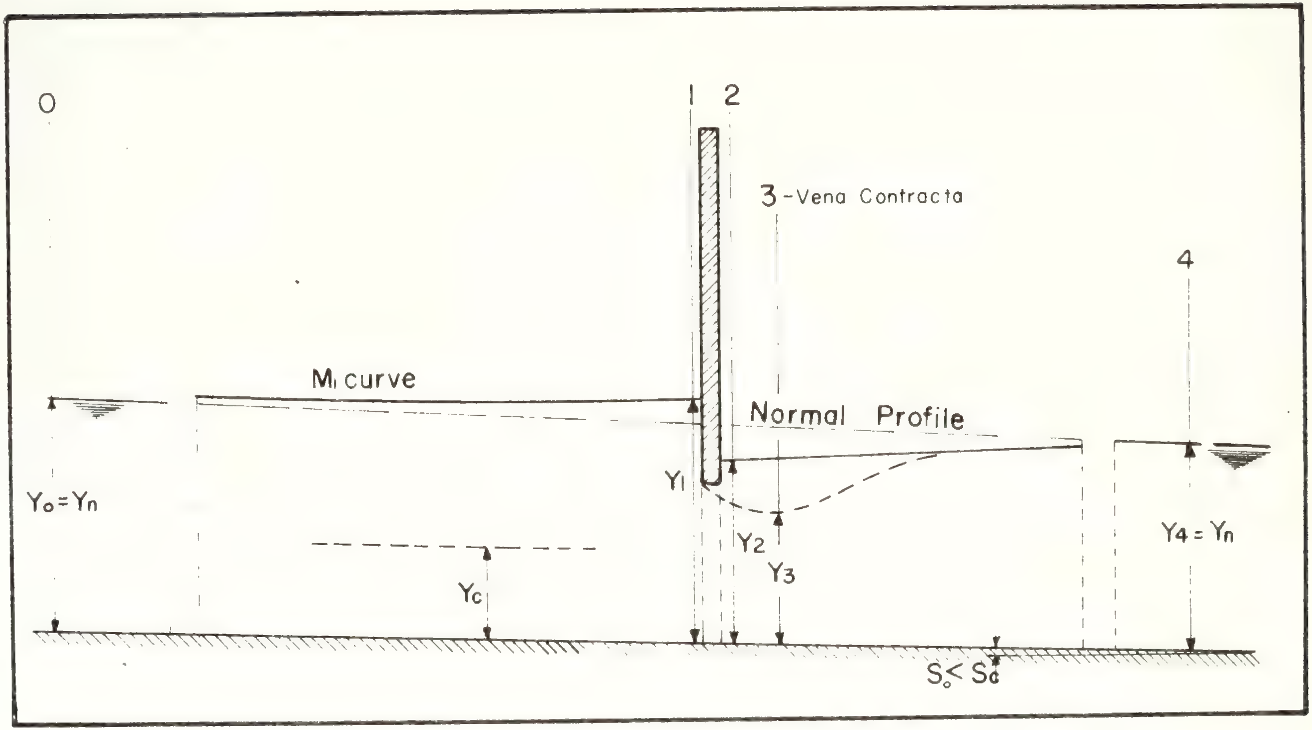
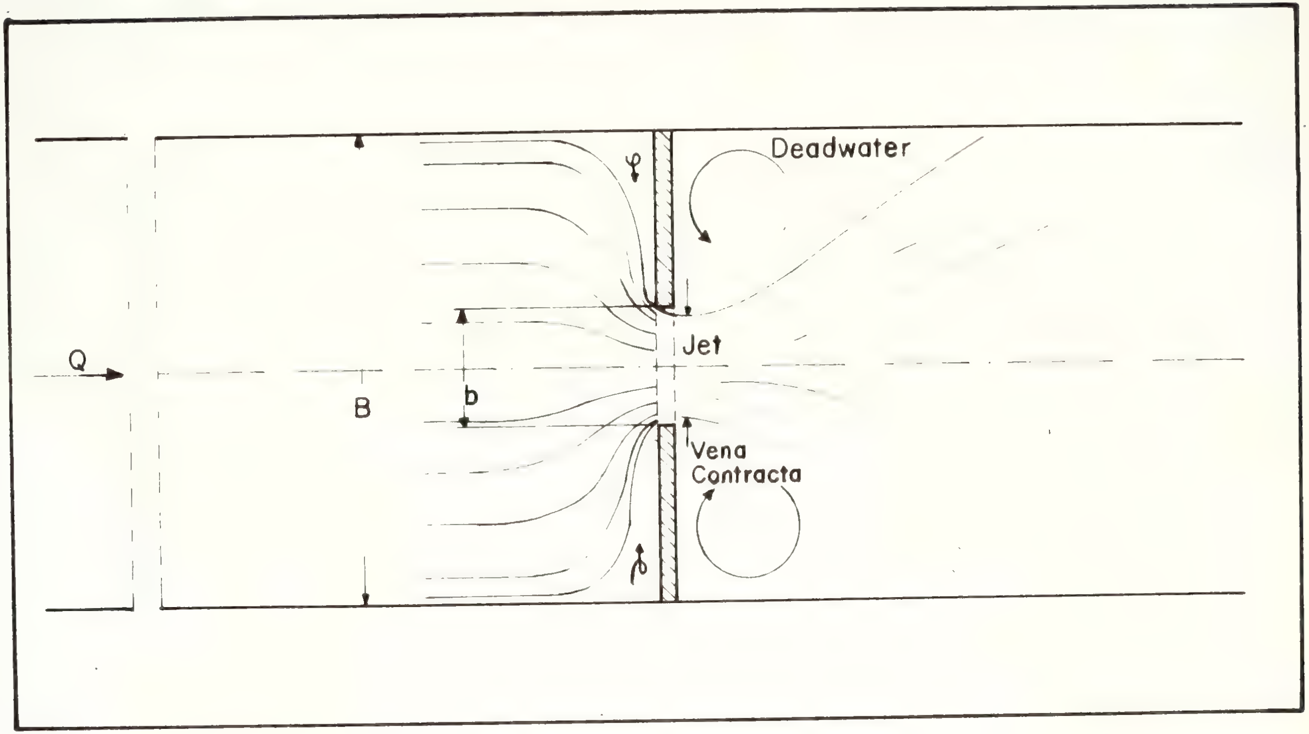


Fig 3.2 Center Line Surface Profile Near Submerged Constriction



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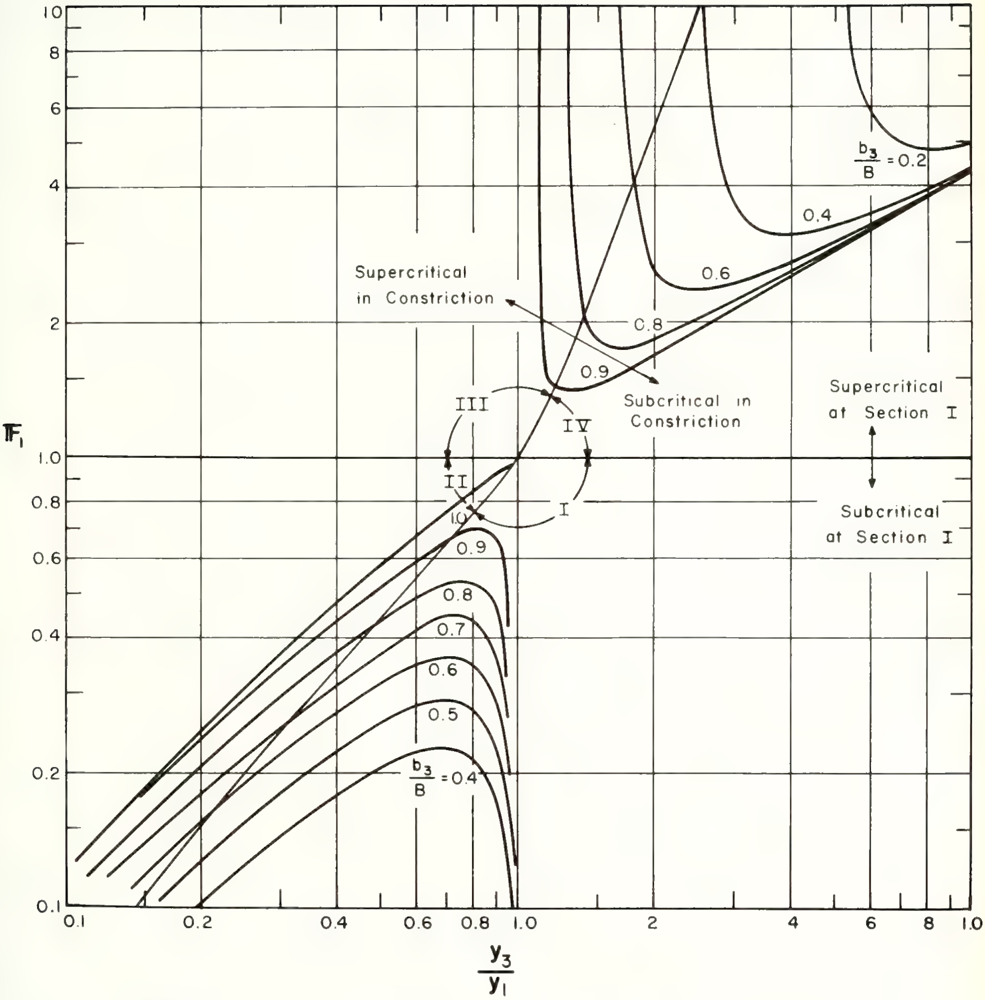


FIGURE 3-4 — CLASSES OF FLOW IN SUDDEN CONTRACTIONS IN OPEN CHANNELS

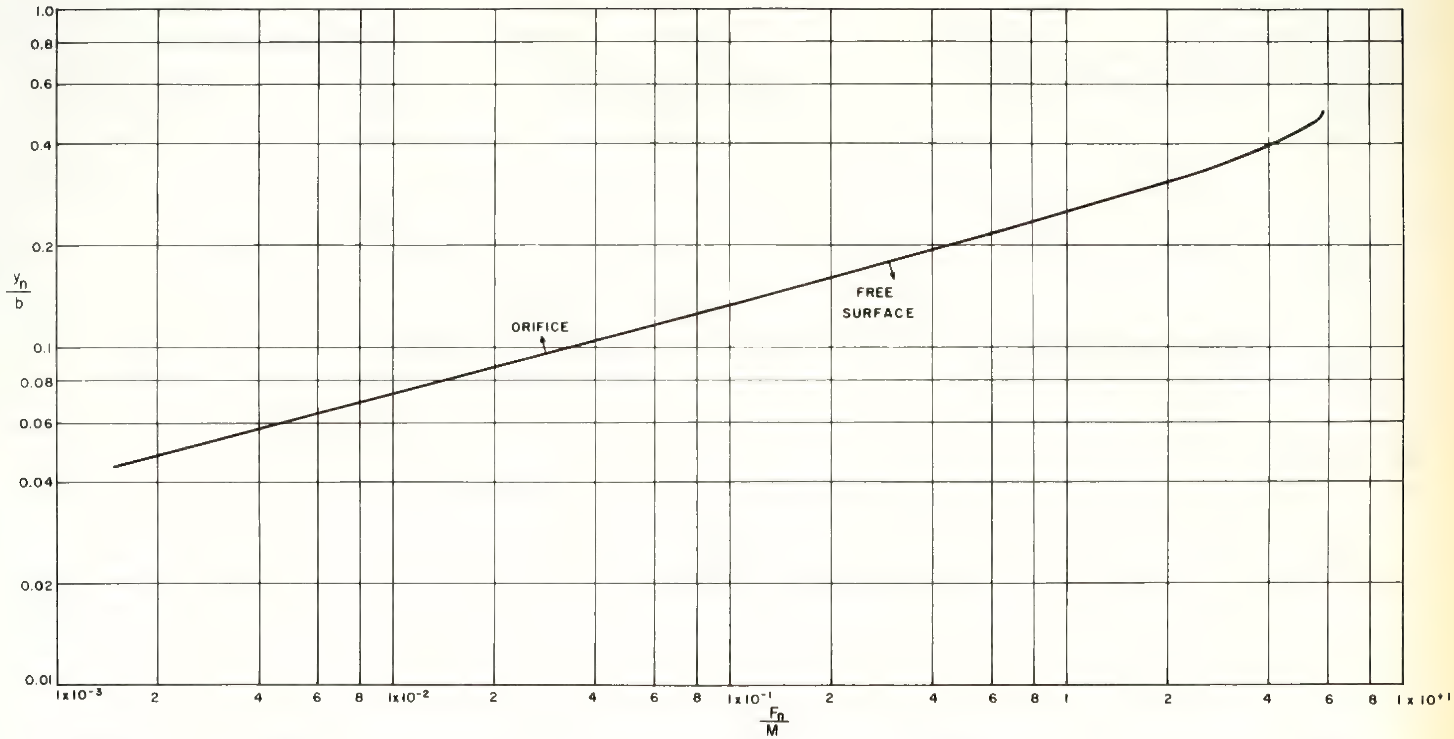


FIGURE 3-5 — EMPIRICAL RELATIONSHIP TO DISTINGUISH BETWEEN FREE SURFACE FLOW AND ORIFICE FLOW

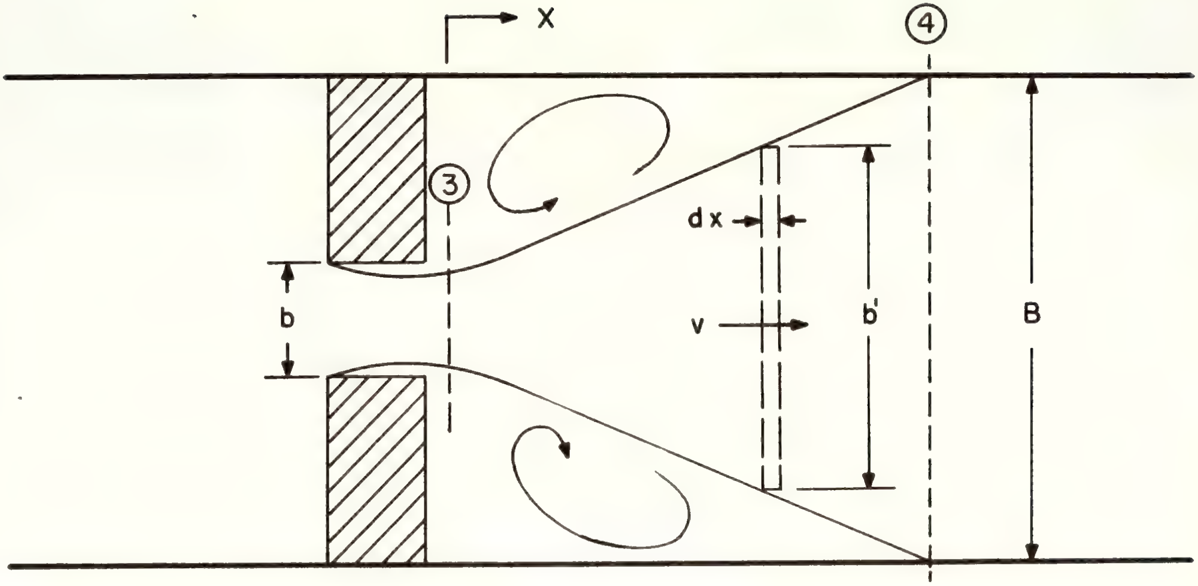


FIGURE 3-6 — DEFINITION SKETCH FOR ANALYSIS OF EXPANDING FLOW

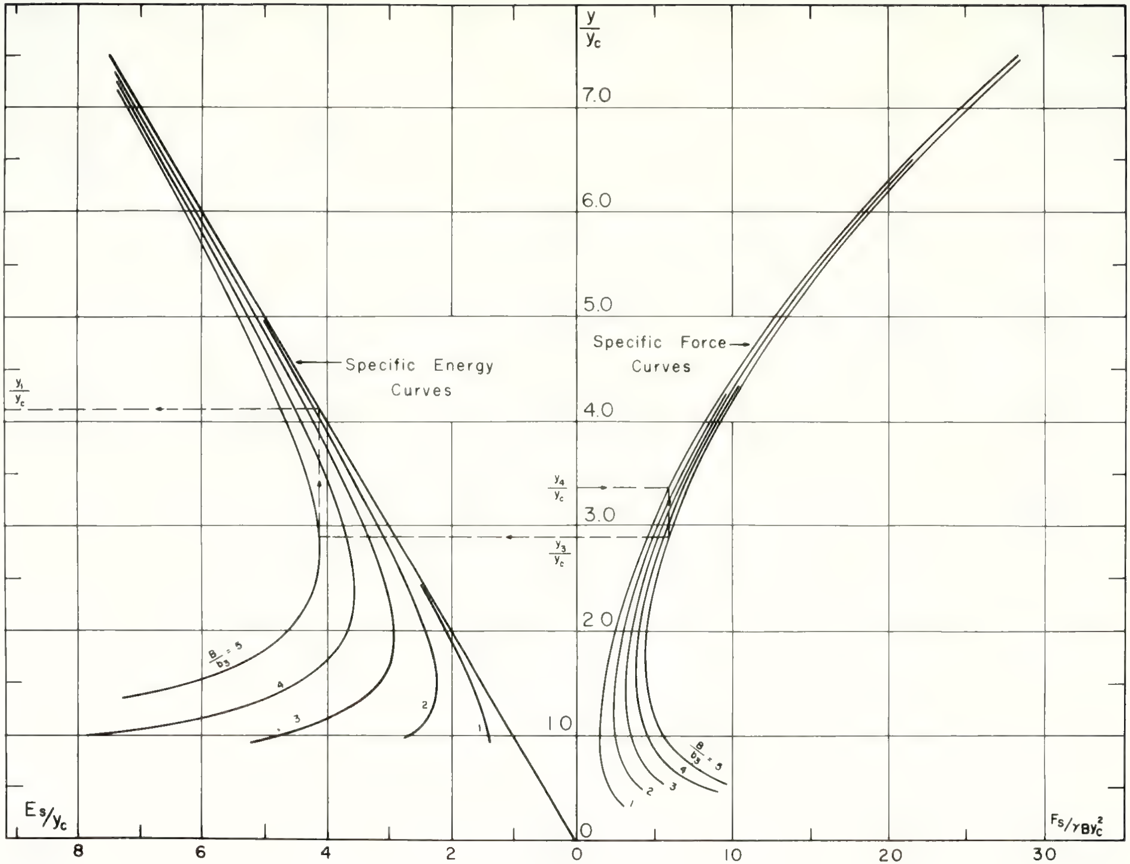


FIGURE 3-7 — GRAPHICAL SOLUTION OF BACKWATER DUE TO A CONSTRICTION

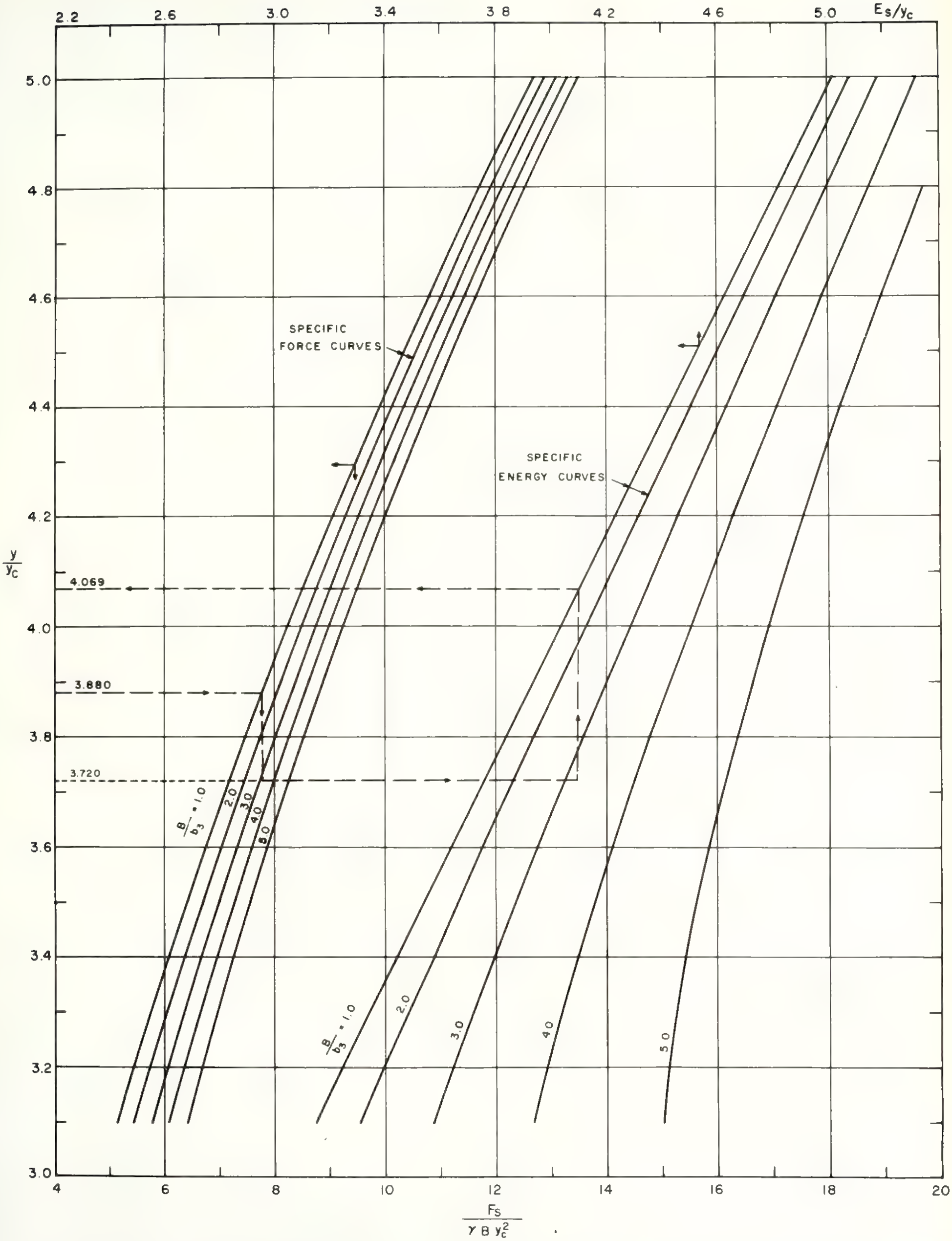


FIGURE 3-8 — DETAIL OF GRAPHICAL SOLUTION OF BACKWATER DUE TO A CONSTRICTION

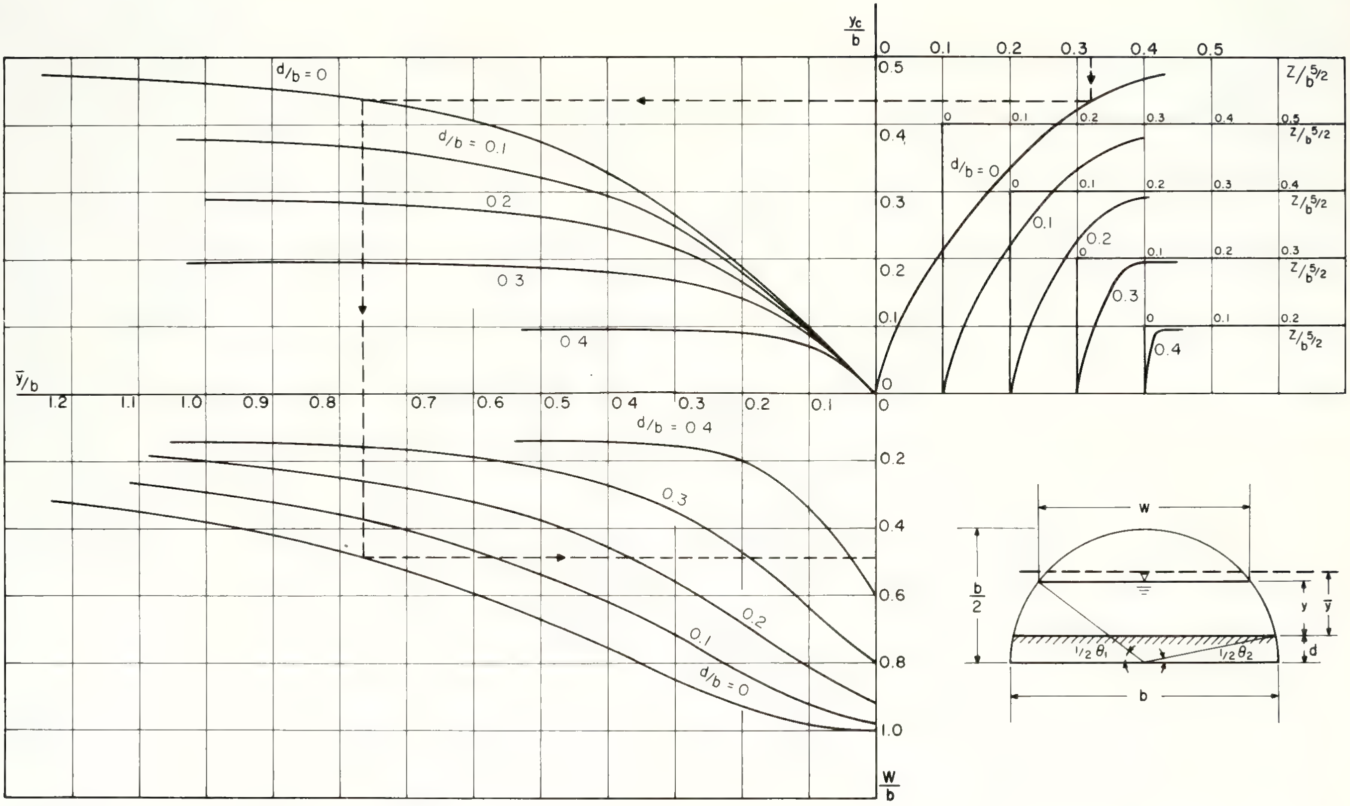


FIGURE 3-9 — GEOMETRIC PROPERTIES OF SEMI-CIRCULAR AND CIRCULAR SEGMENT ARCHES

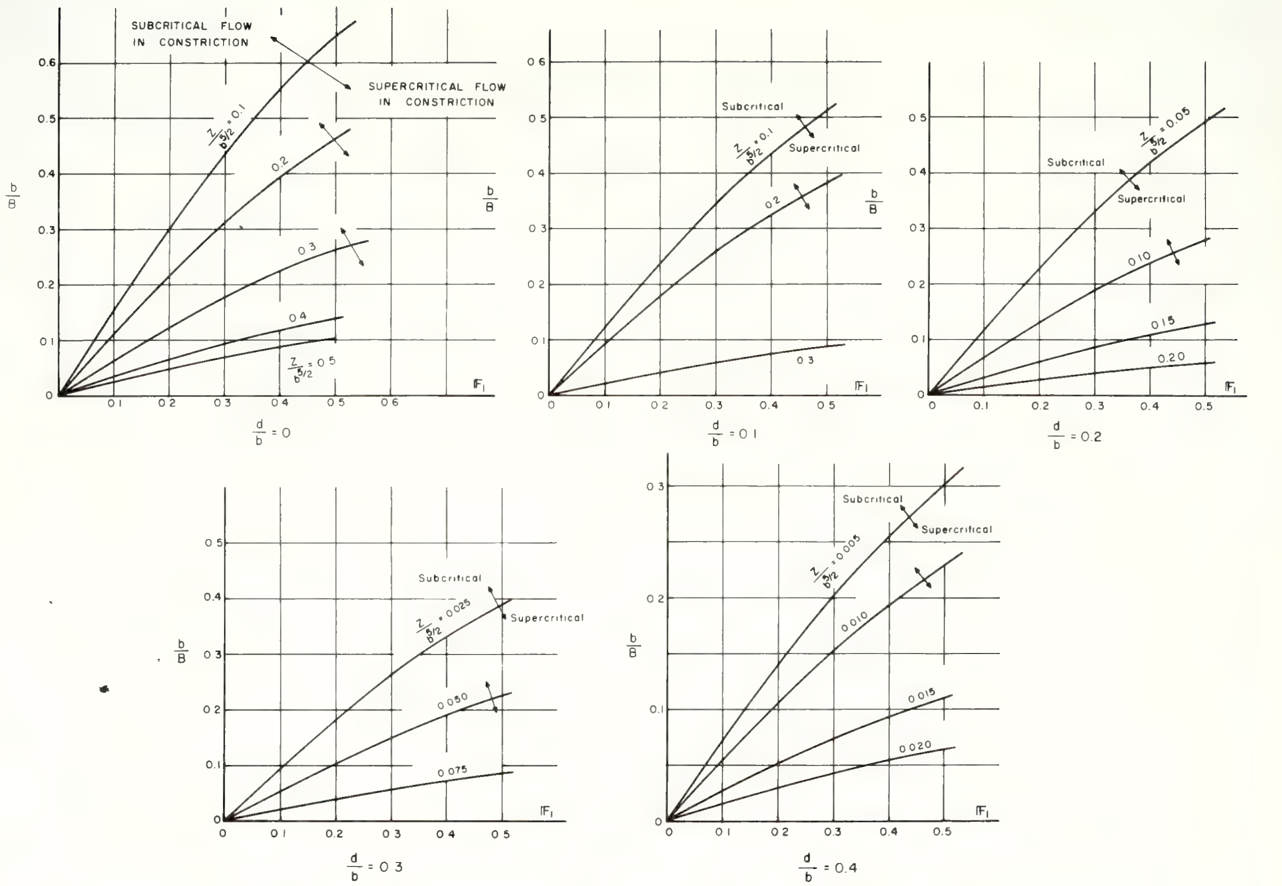


FIGURE 3-10 — LIMITING BACKWATER - BOUNDARY BETWEEN FLOWS OF CLASSES I & II SEMI - CIRCULAR AND CIRCULAR SEGMENT ARCHES

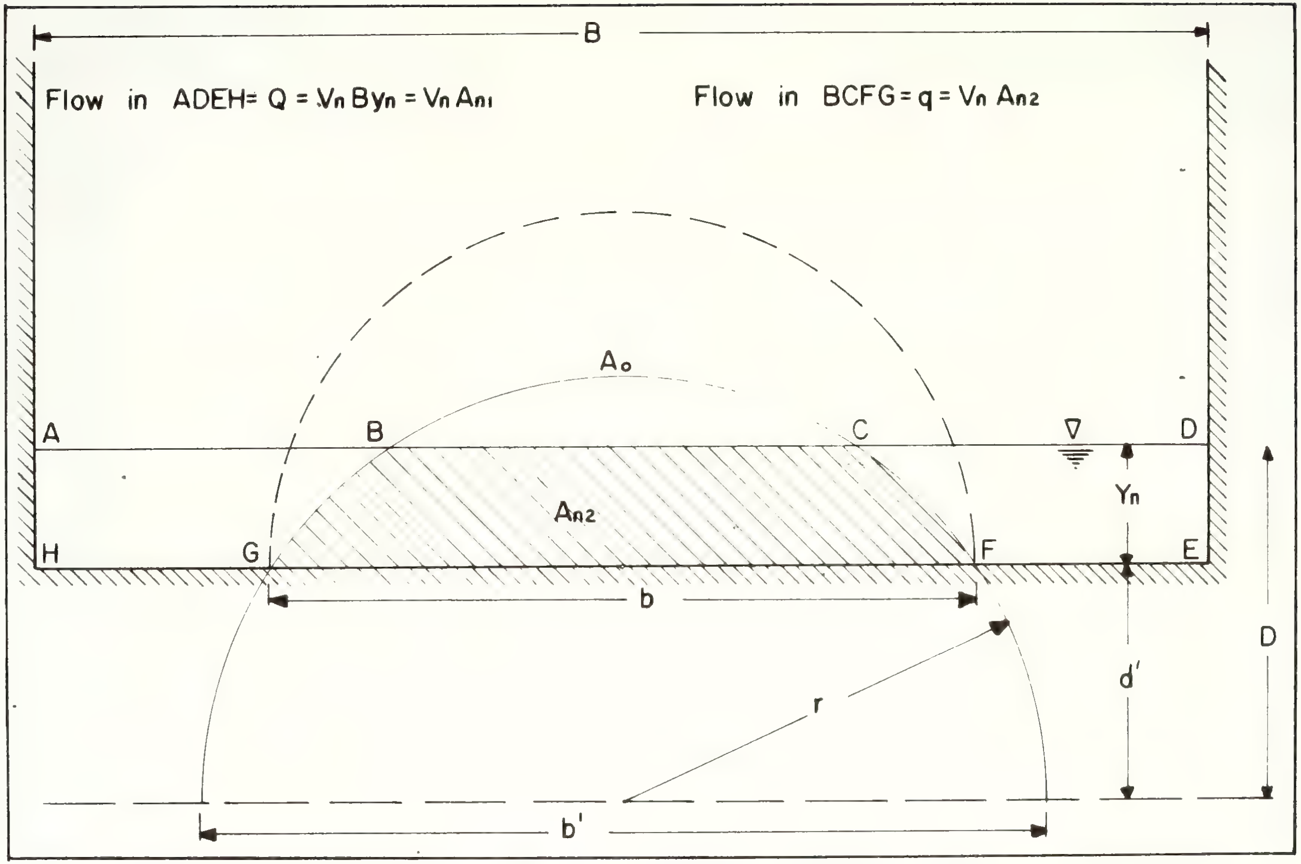


Fig 3·11 Definition Sketch for the Channel Opening Ratio

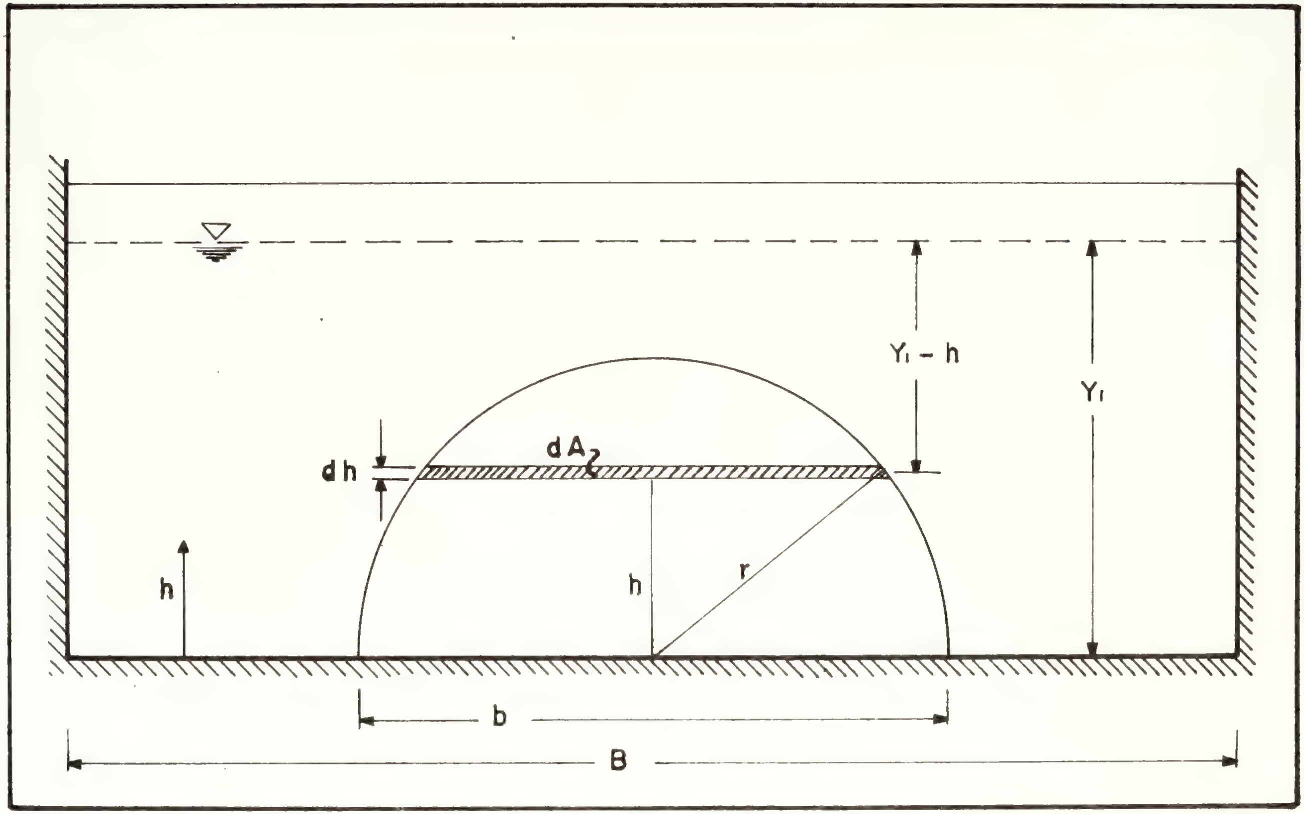
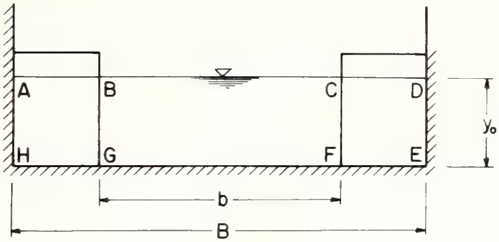
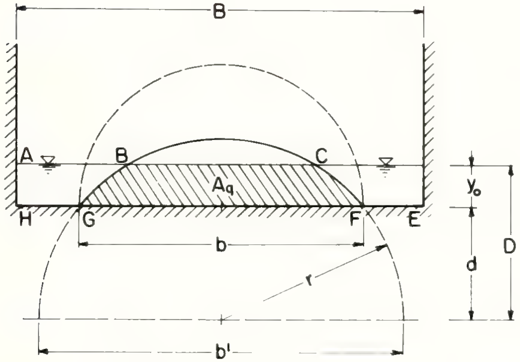


FIG 3-11a DEFINITION SKETCH FOR ORIFICE FLOW CALCULATION



FLOW IN ADEH = $Q = V_o B y_o$

FLOW IN BCFG = $q = V_o b y_o$



FLOW IN ADEH = $Q = V_o B y_o$

FLOW IN BCFG = $q = V_o b y_o$

DEFINITION SKETCH FOR THE DEVELOPMENT OF THE CONTRACTION RATIO

Figure 3-12

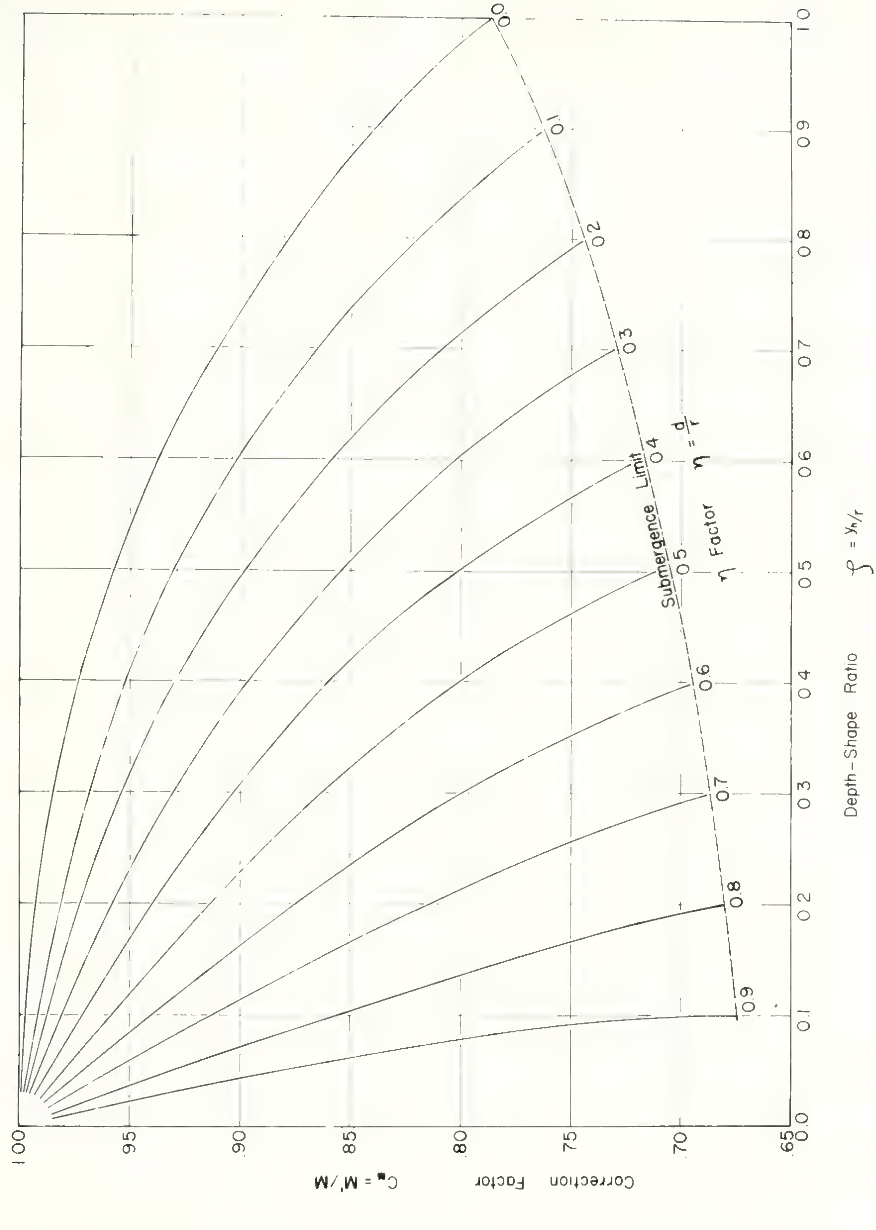


FIGURE 3-13 CORRECTION COEFFICIENT FOR THE CHANNEL OPENING RATIO

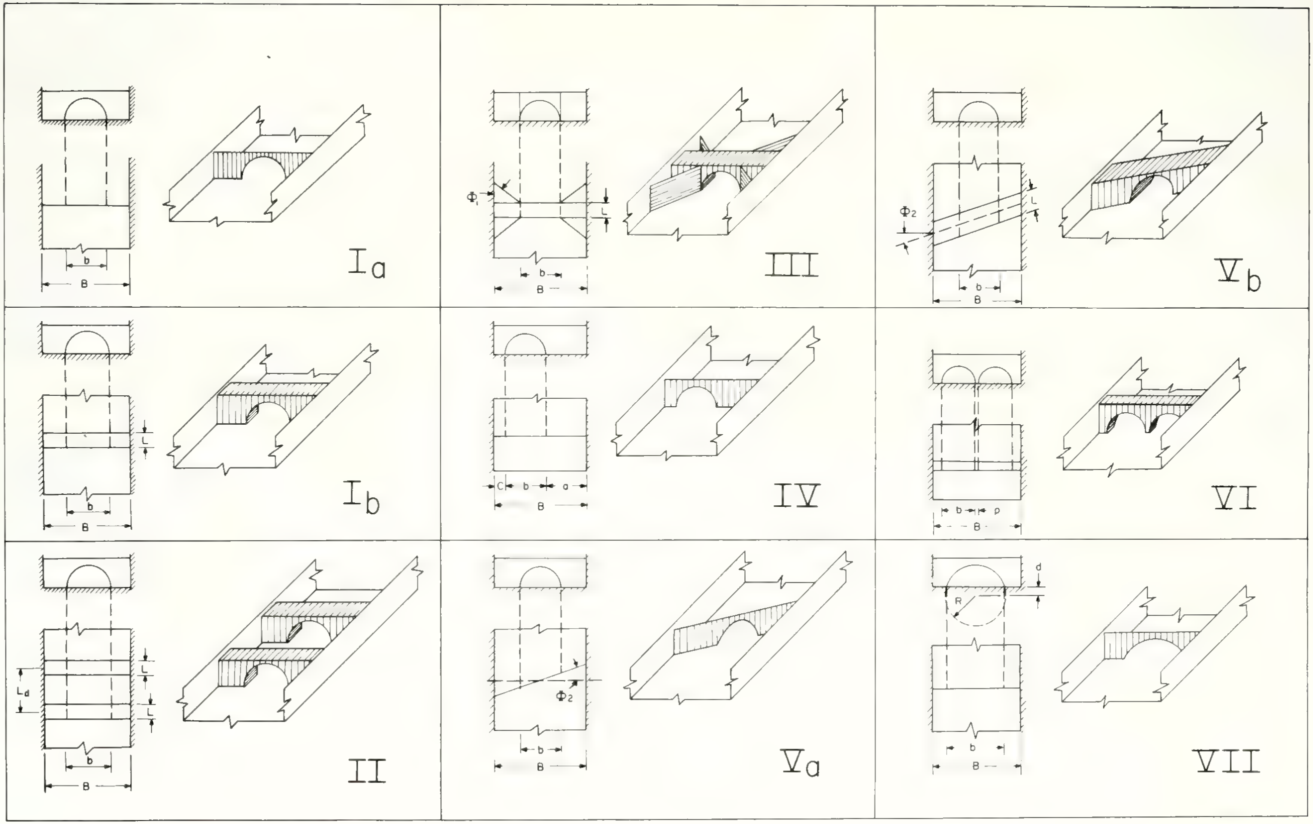
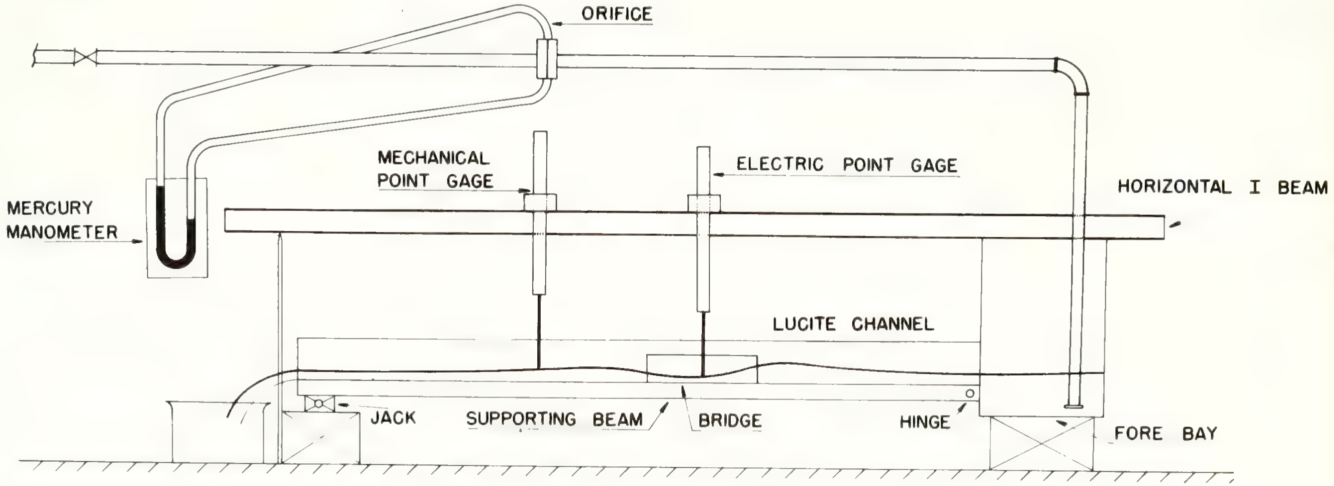
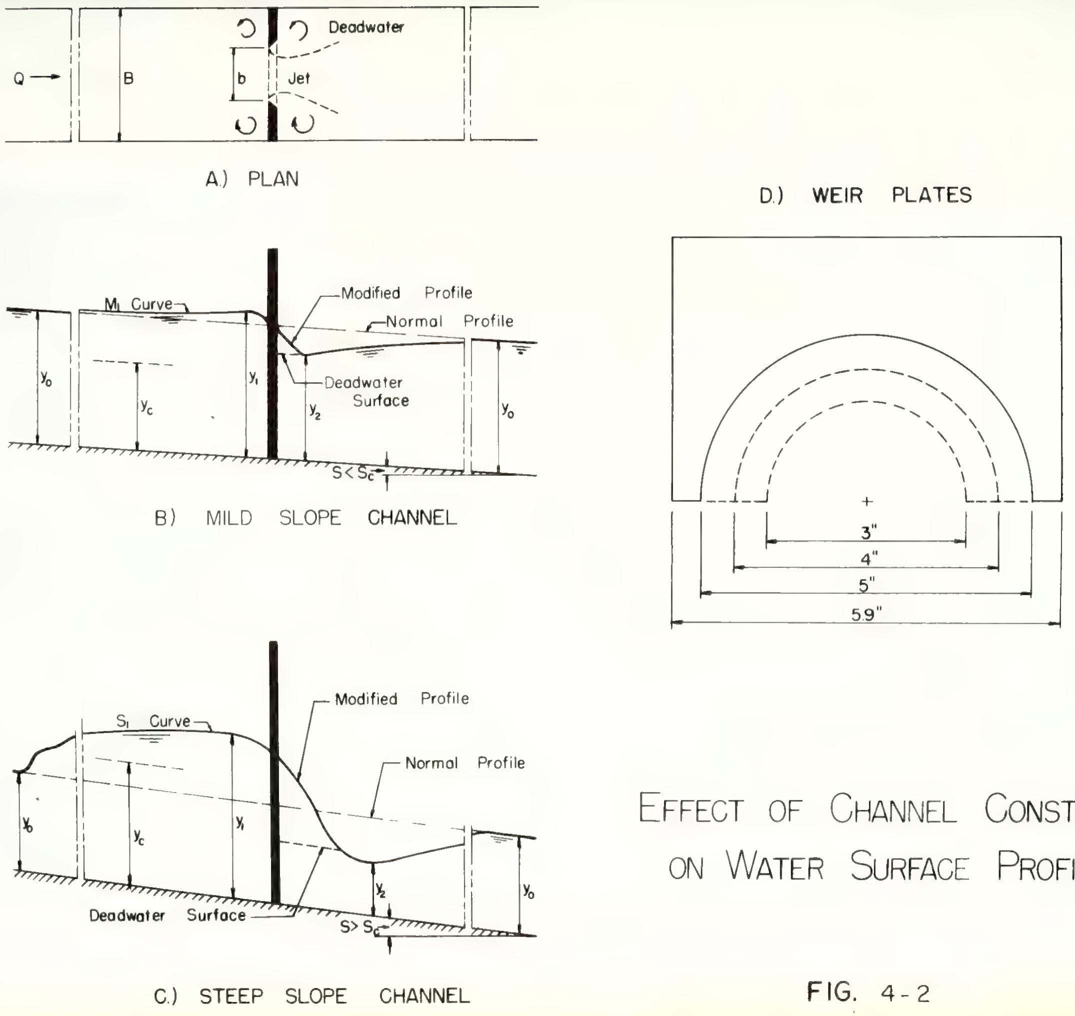


FIGURE 3-14 DEFINITION SKETCHES OF TEST GEOMETRIES



PRELIMINARY FLUME

FIG. 4-1



EFFECT OF CHANNEL CONSTRICTION ON WATER SURFACE PROFILE

FIG. 4-2

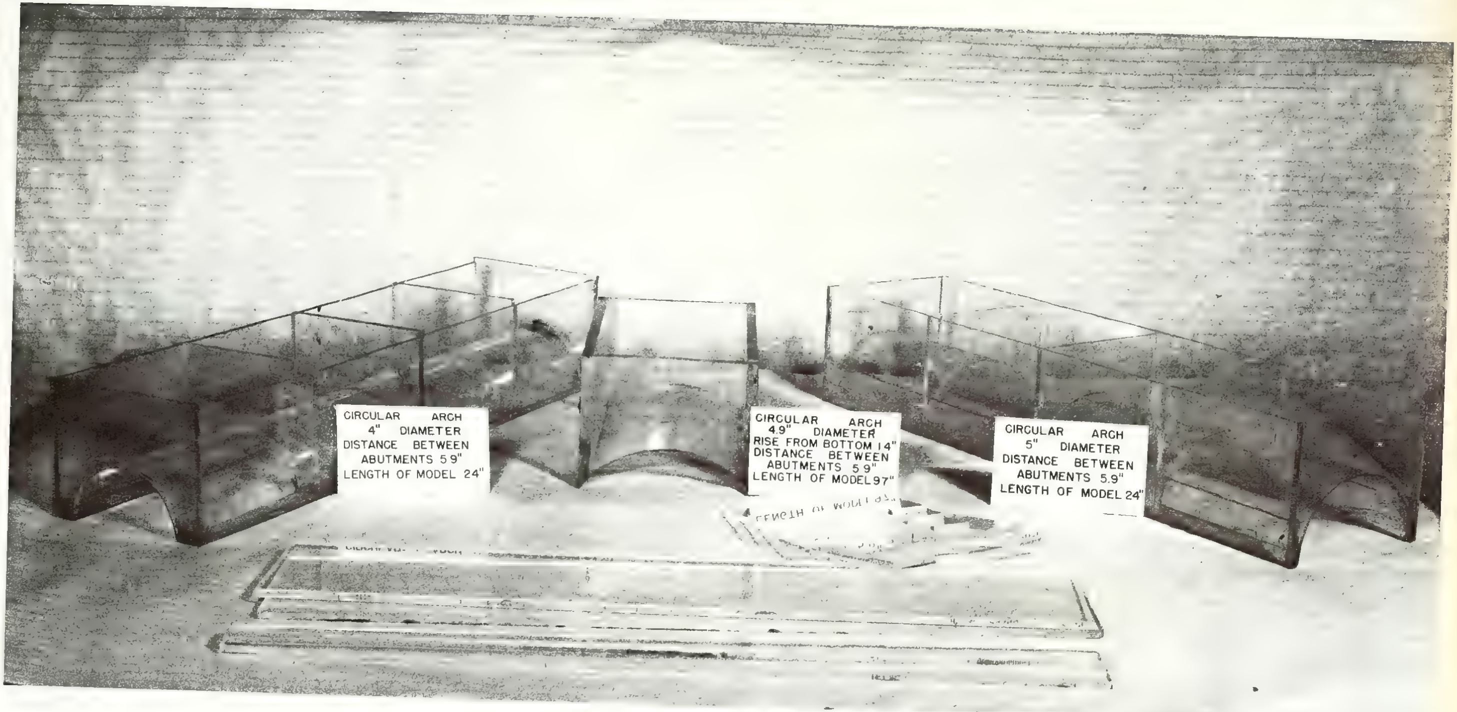


FIGURE 4-3 THREE DIMENSIONAL MODELS FOR PRELIMINARY STUDIES

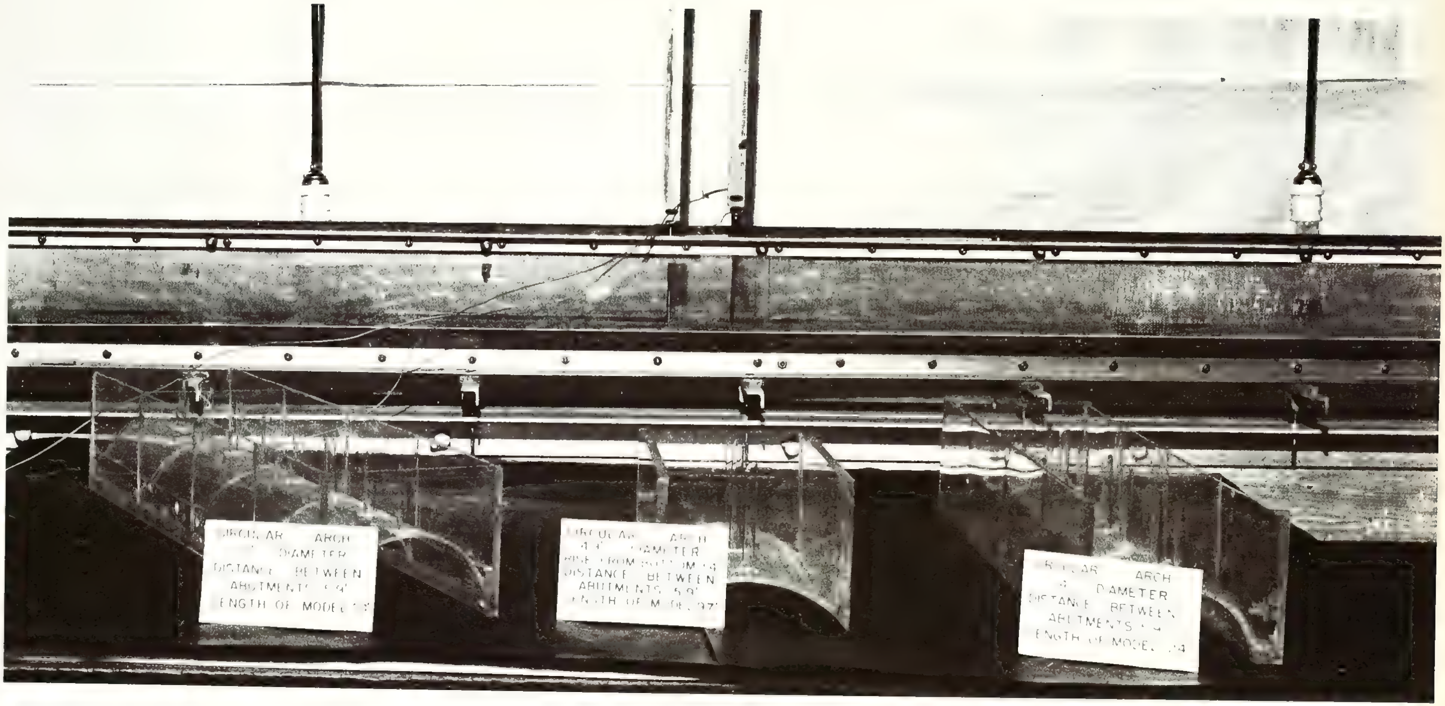
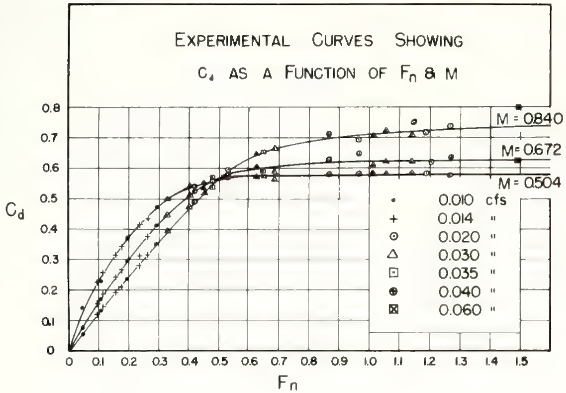


FIGURE 4-4 SMALL FLUME WITH ARTIFICIAL ROUGHNESS INSTALLED, and MECHANICAL AND ELECTRICAL GAGES



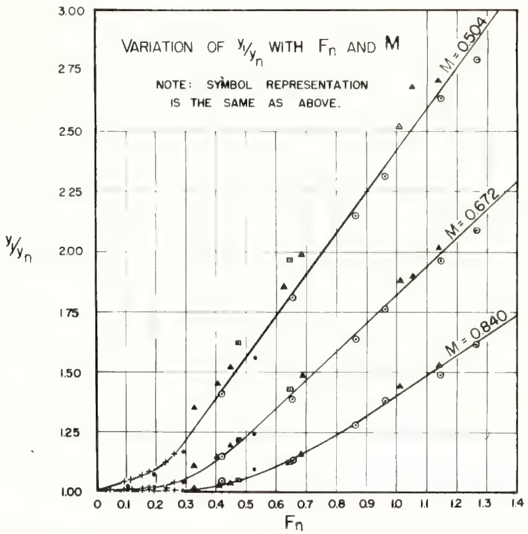
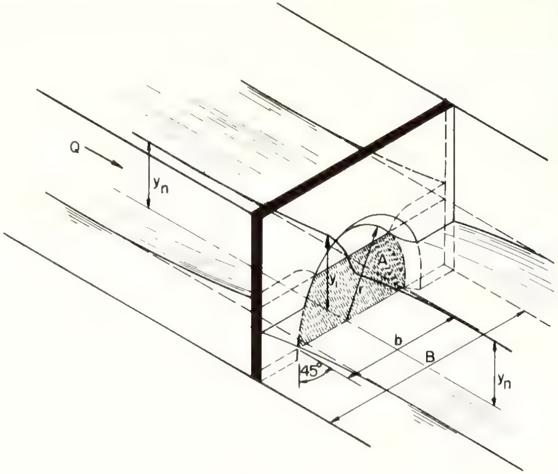


FIG. 4-5



$$Q = C y_1^{3/2} b T \qquad (1)$$

$$C = c_d \sqrt{2g}\ 17/24$$

$$T = \left[1 - 0.1294(y_1/r)^2 - 0.0177(y_1/r)^4 + \cdots\right]$$

$$y_1/y_n = \left(F_n \sqrt{g} / C_M A\right)^{2/3} \qquad (2)$$

$$F_n = V_n / \sqrt{g y_n}$$

$$M = b/B$$

SEMICIRCULAR WEIR TESTS

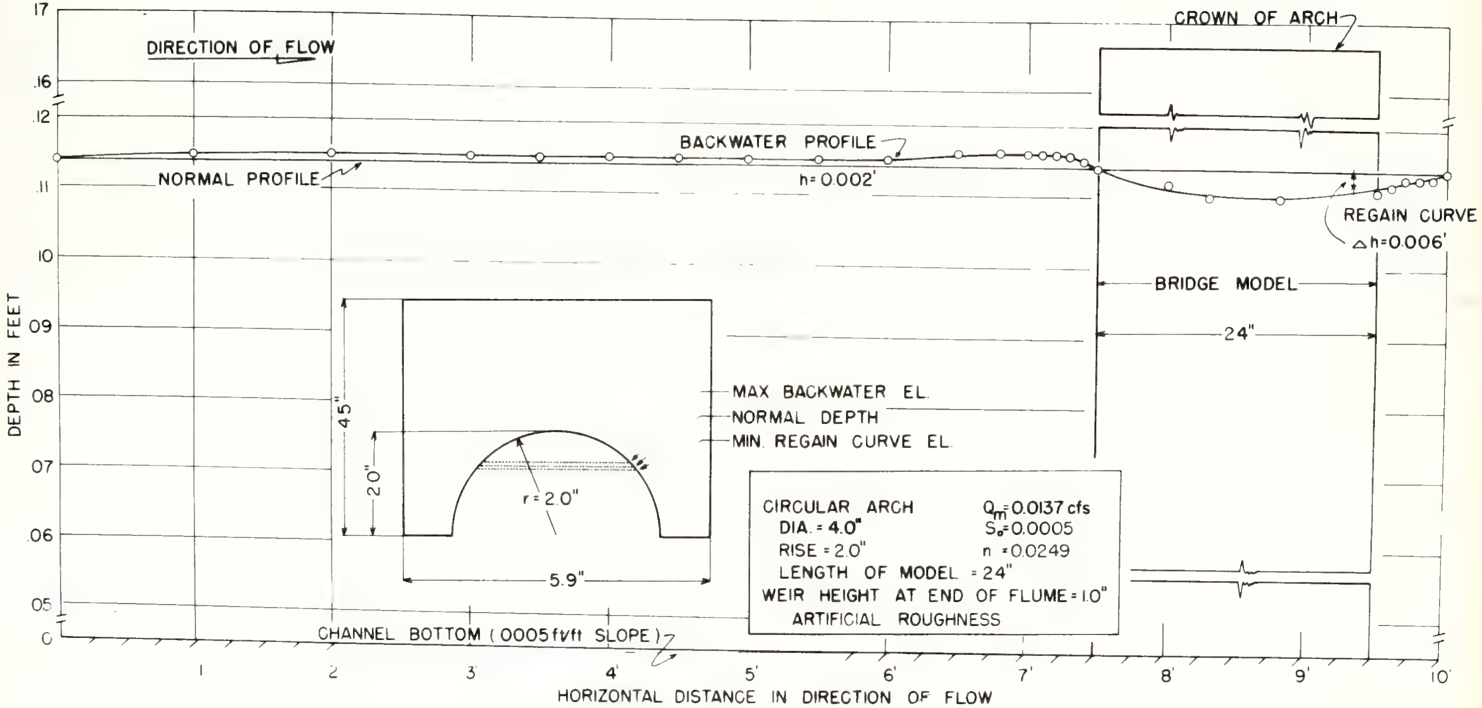
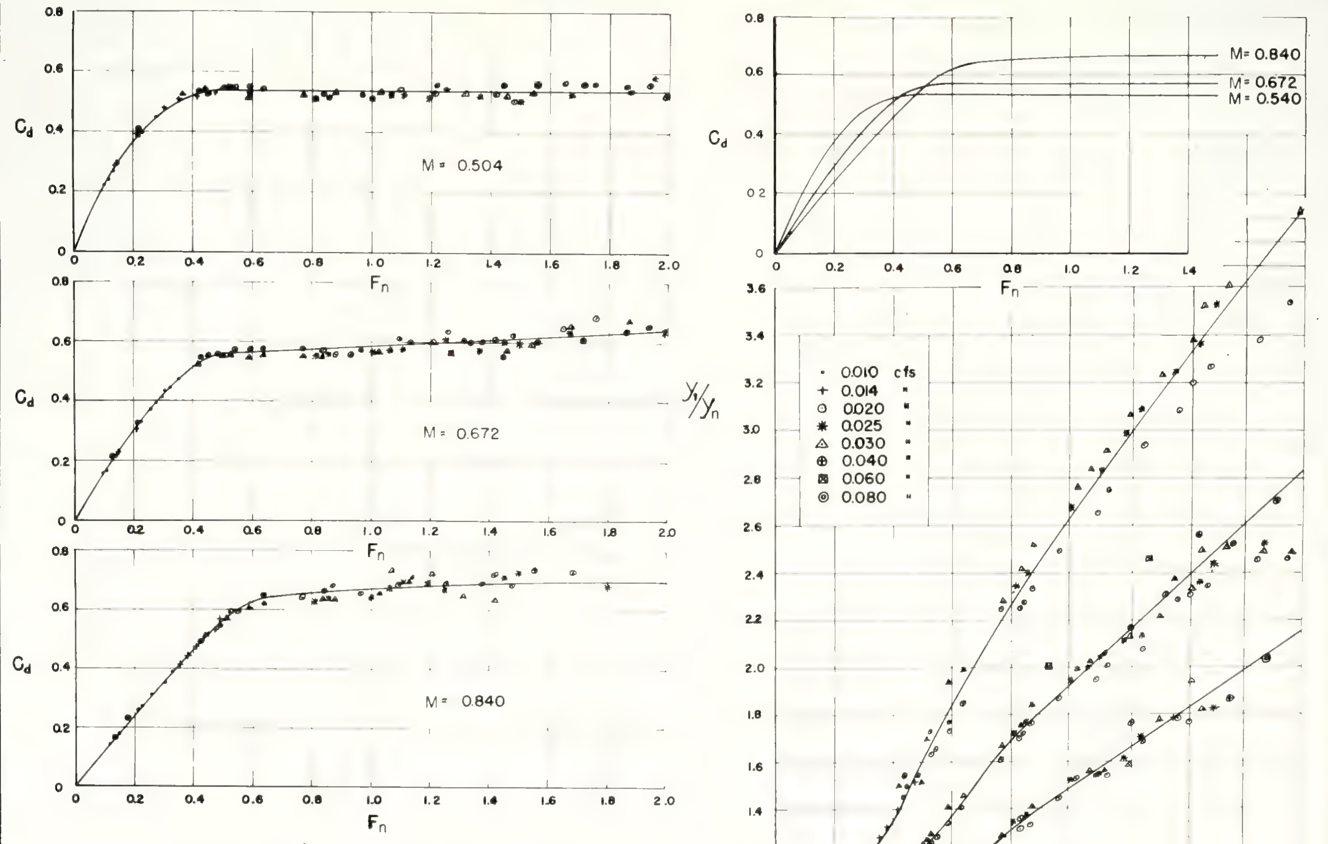
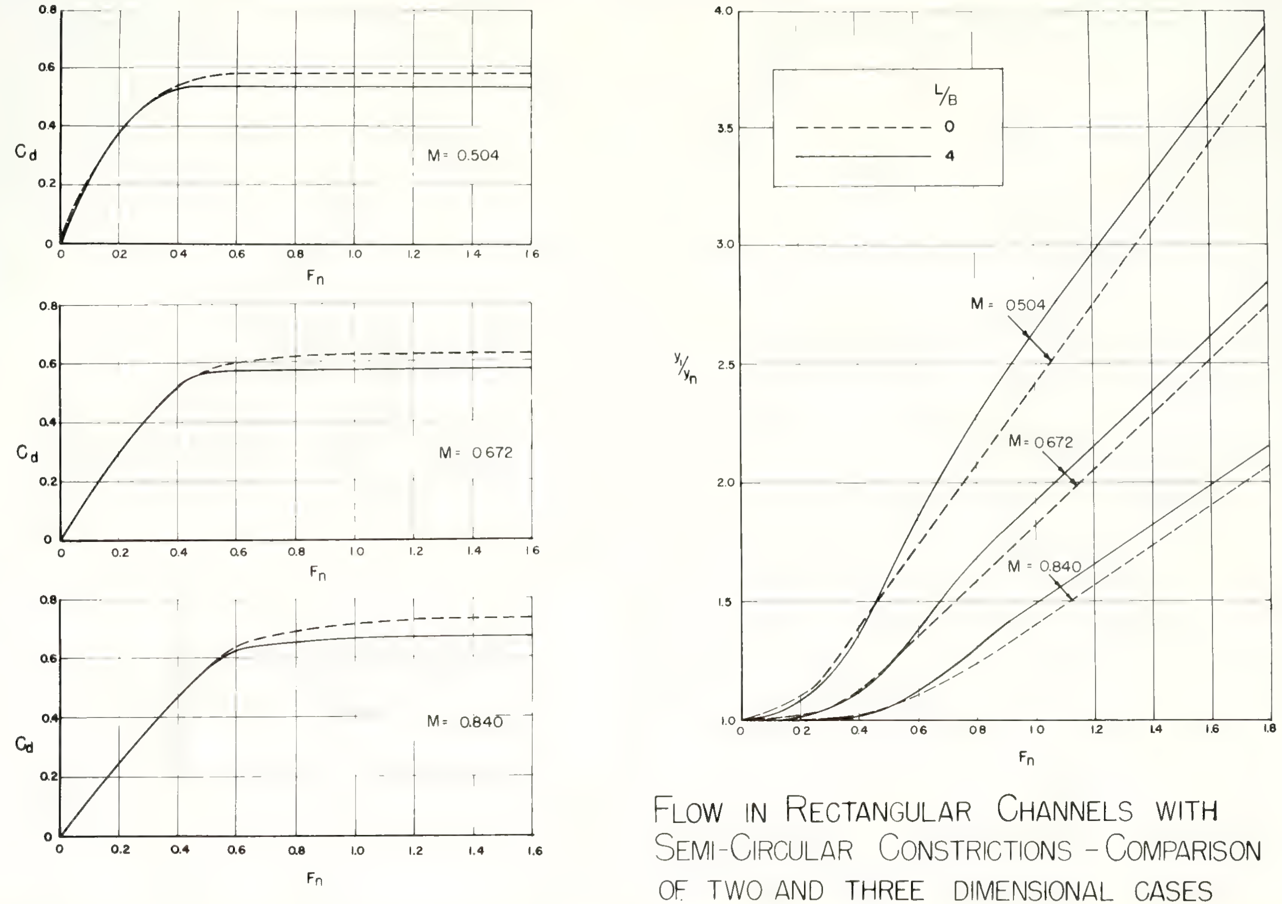

DIRECTION OF FLOW
CROWN OF ARCH
BACKWATER PROFILE
NORMAL PROFILE
h= 0.002'
REGAIN CURVE
△h=0.006'
BRIDGE MODEL
24"
MAX BACKWATER EL.
NORMAL DEPTH
MIN. REGAIN CURVE EL.
45"
2.0"
r = 2.0"
5.9"
CIRCULAR ARCH
DIA. = 4.0"
RISE = 2.0"
LENGTH OF MODEL = 24"
WEIR HEIGHT AT END OF FLUME = 1.0"
ARTIFICIAL ROUGHNESS
Q_m= 0.0137 cfs
S_o= 0.0005
n = 0.0249
CHANNEL BOTTOM (.0005 ft/ft SLOPE)
DEPTH IN FEET
.17
.16
.12
.11
.10
.09
.08
.07
.06
.05
0
1
2
3'
4'
5'
6'
7'
8'
9'
10'
HORIZONTAL DISTANCE IN DIRECTION OF FLOW

FIG. 4-6



SEMI-CIRCULAR ARCH BRIDGE MODEL TESTS

FIG. 4-7



FLOW IN RECTANGULAR CHANNELS WITH SEMI-CIRCULAR CONSTRICTIONS - COMPARISON OF TWO AND THREE DIMENSIONAL CASES

FIG. 4 - 8

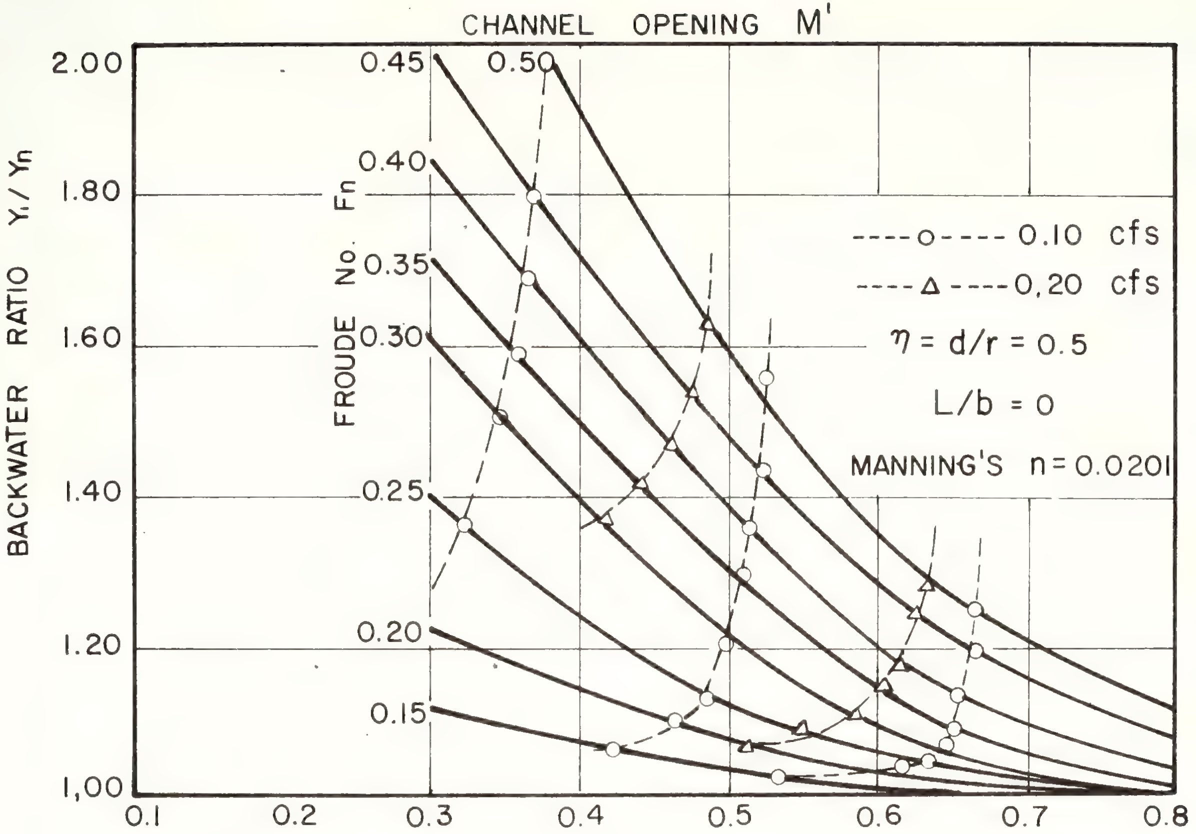
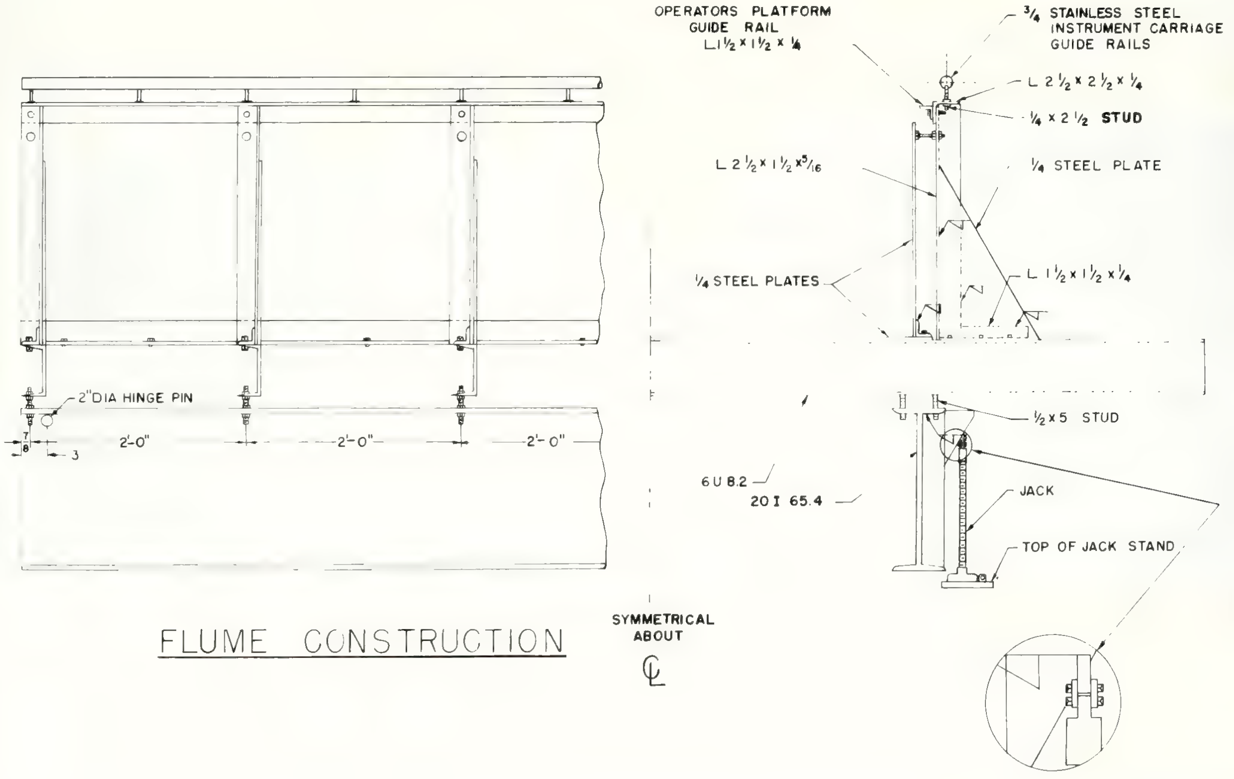


FIG 4-8a VARIATION OF THE BACKWATER RATIO FOR SEGMENT ARCHES - SMALL FLUME - ROUGH BOUNDARIES



FLUME CONSTRUCTION

FIGURE 5-1

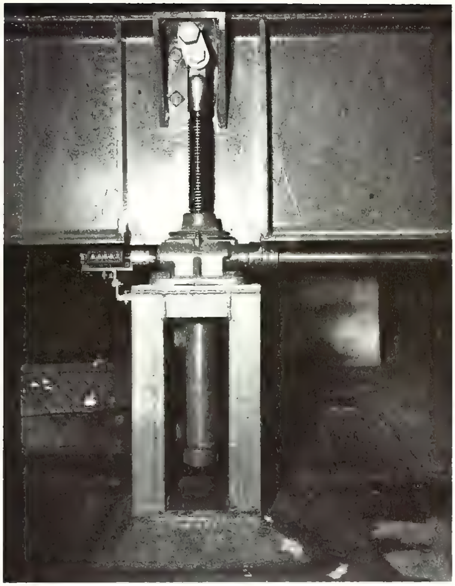


FIG 5-2 JACK DETAIL

FIG 5-3 TAIL GATE

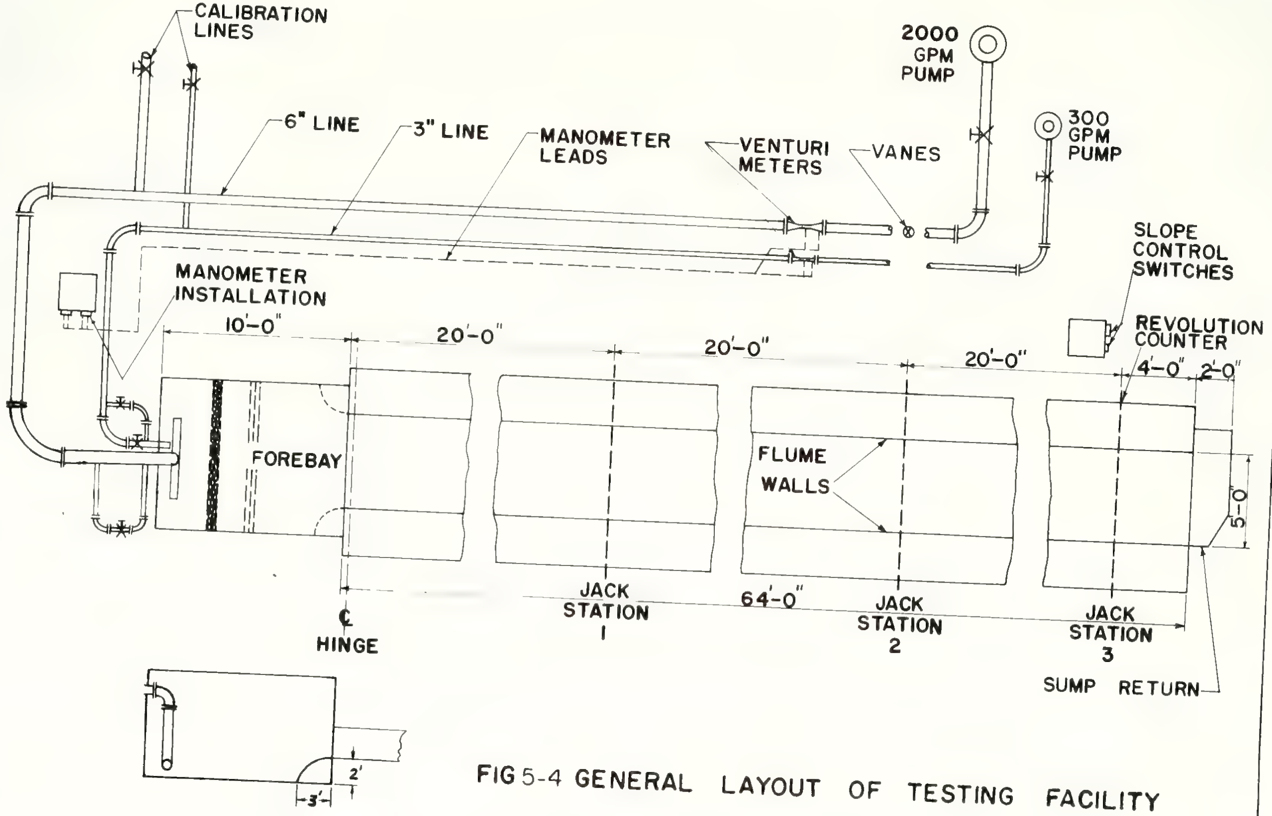


FIG 5-4 GENERAL LAYOUT OF TESTING FACILITY

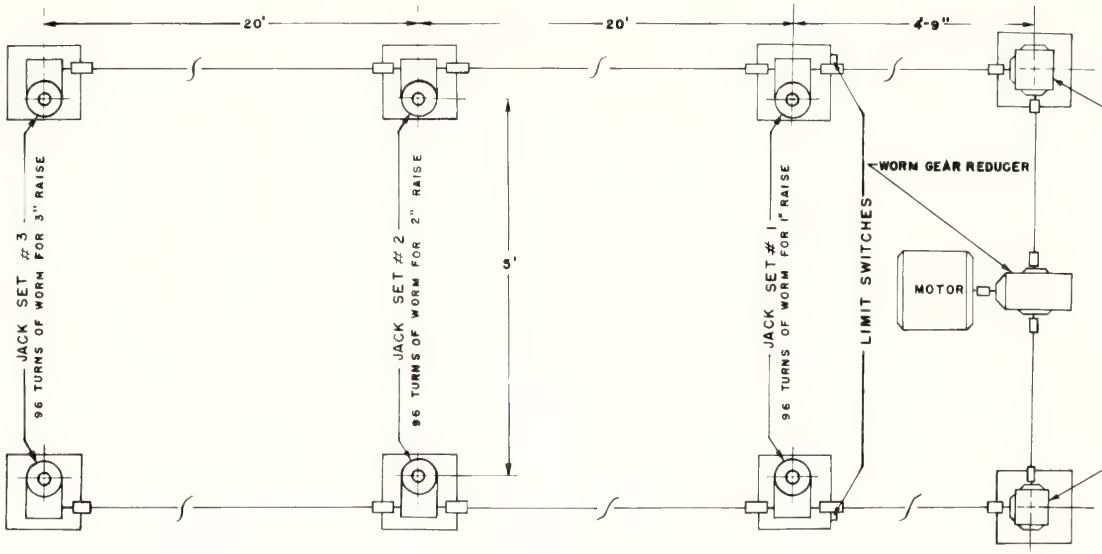


FIG. 5-5 PLAN VIEW OF JACKS AND GEARS

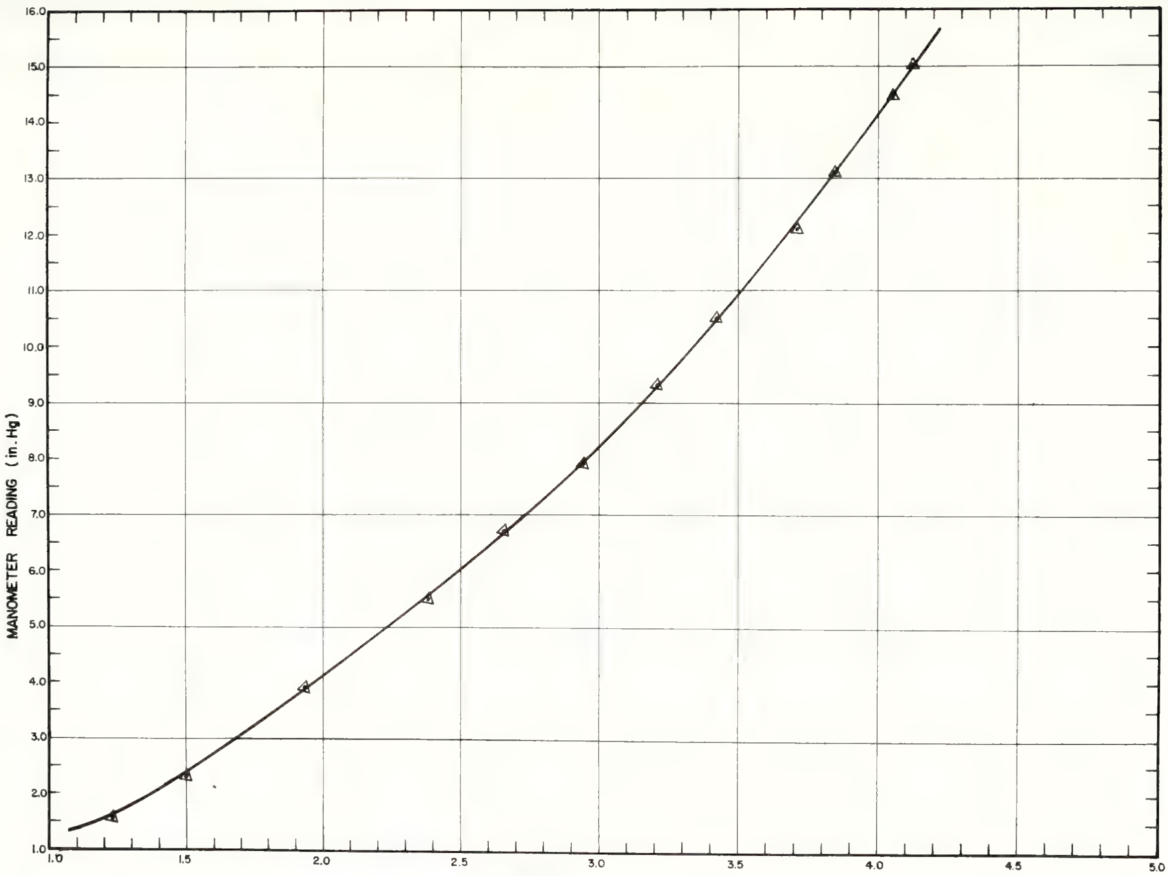


FIG. 5-6 CALIBRATION CURVE FOR 6" VENTURIMETER

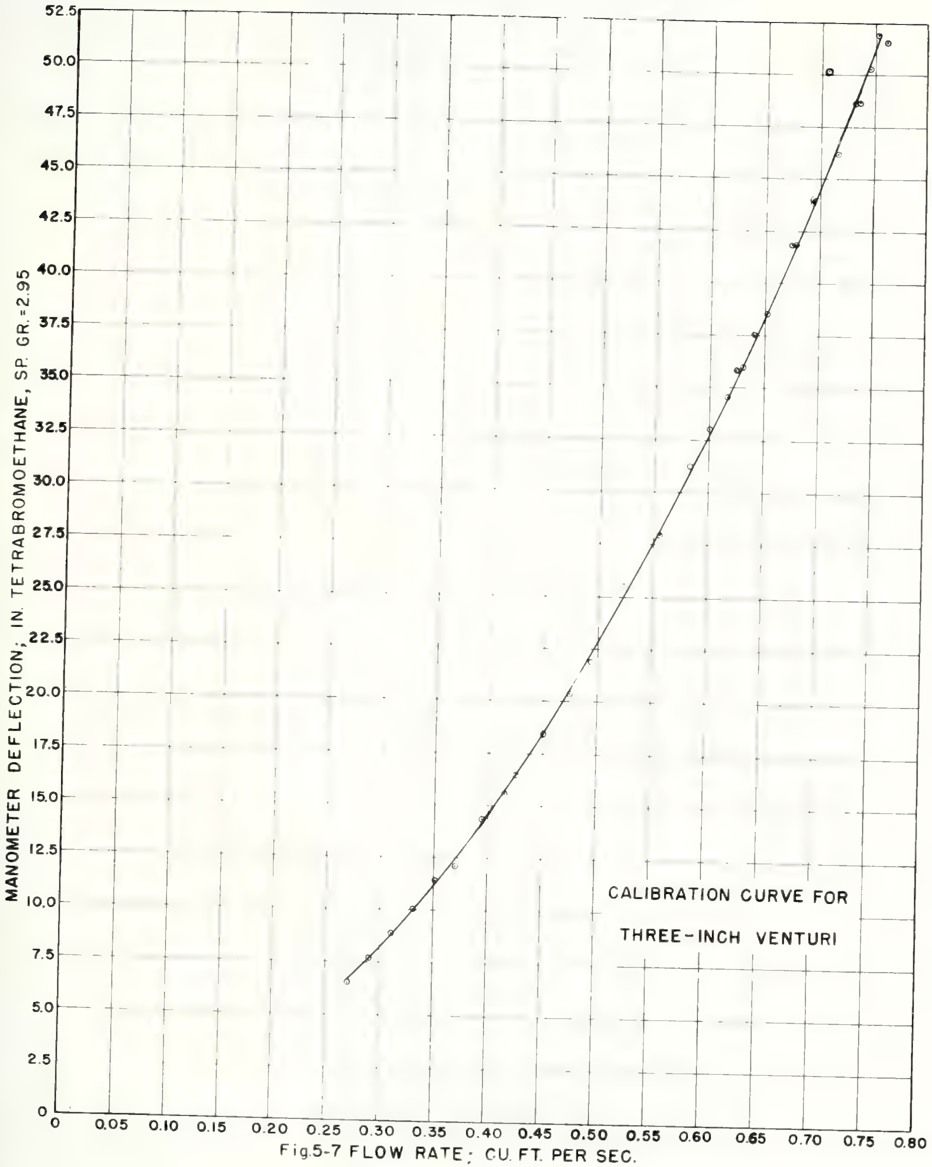


Fig.5-7 FLOW RATE; CU. FT. PER SEC.

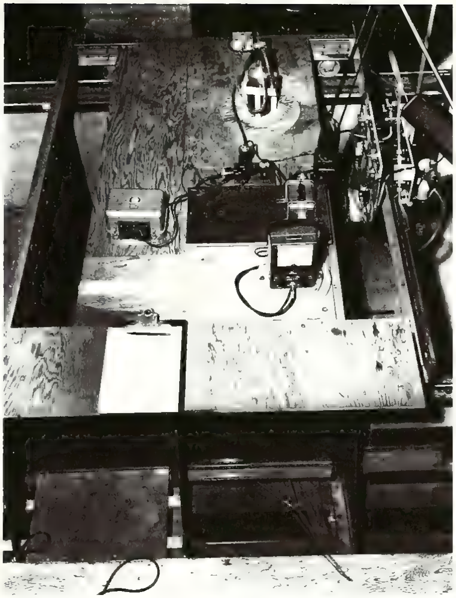


FIG 5-8 TOP VIEW OF INSTRUMENT CARRIAGE

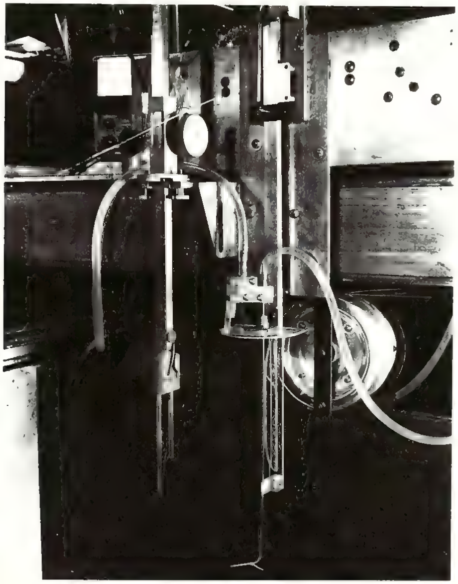


FIG 5-9 POINT GAGE AND PRANDTL TUBE

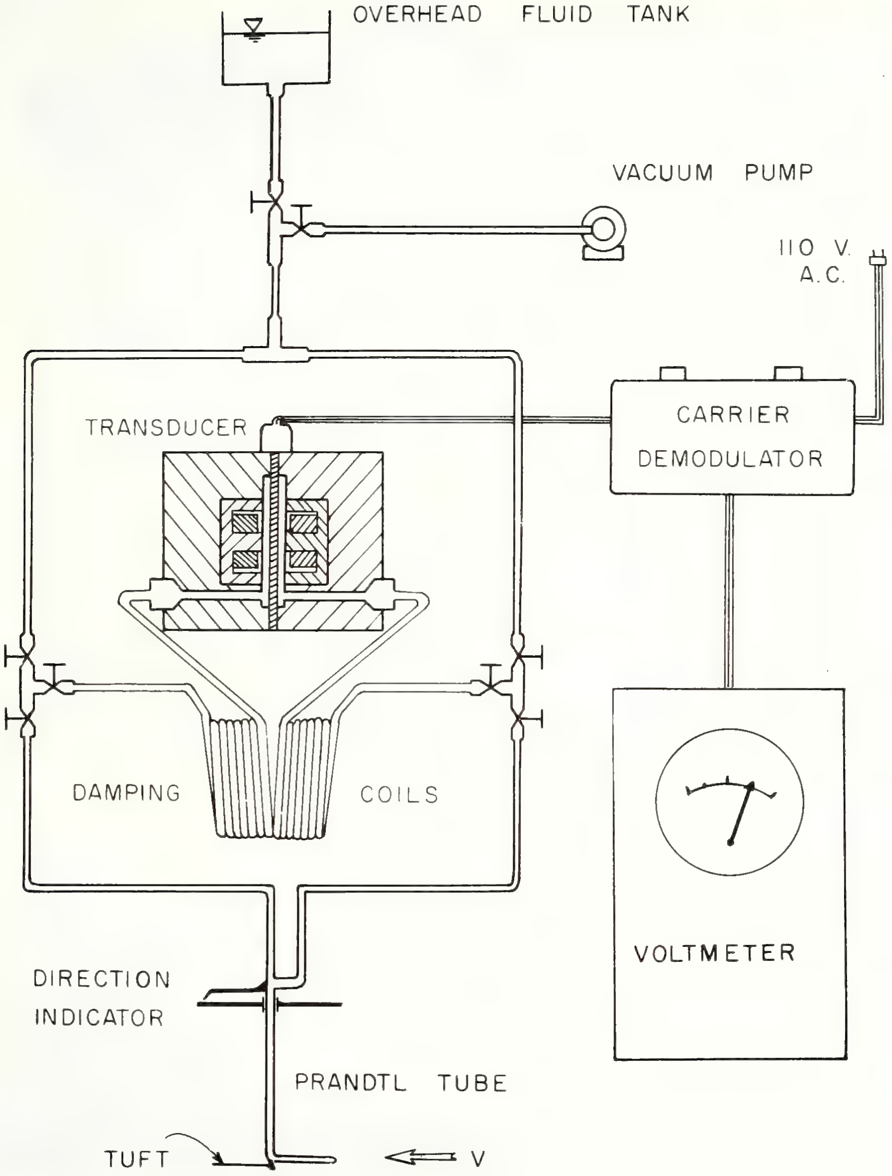


FIGURE 5-10 VELOCITY TRANSDUCER SYSTEM

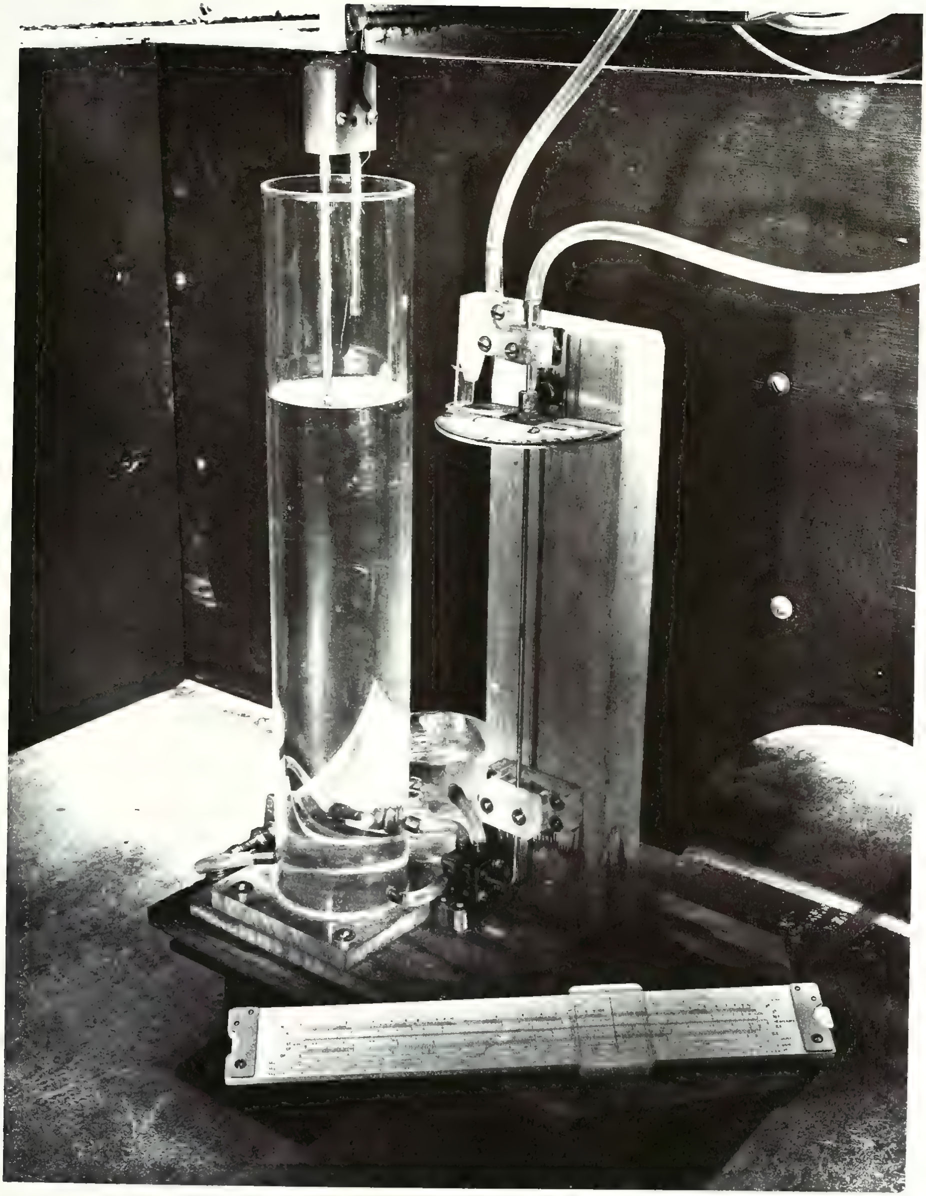


FIG 5-11 CALLIBRATION APPARATUS FOR VELOCITY TRANSDUCER SYSTEM

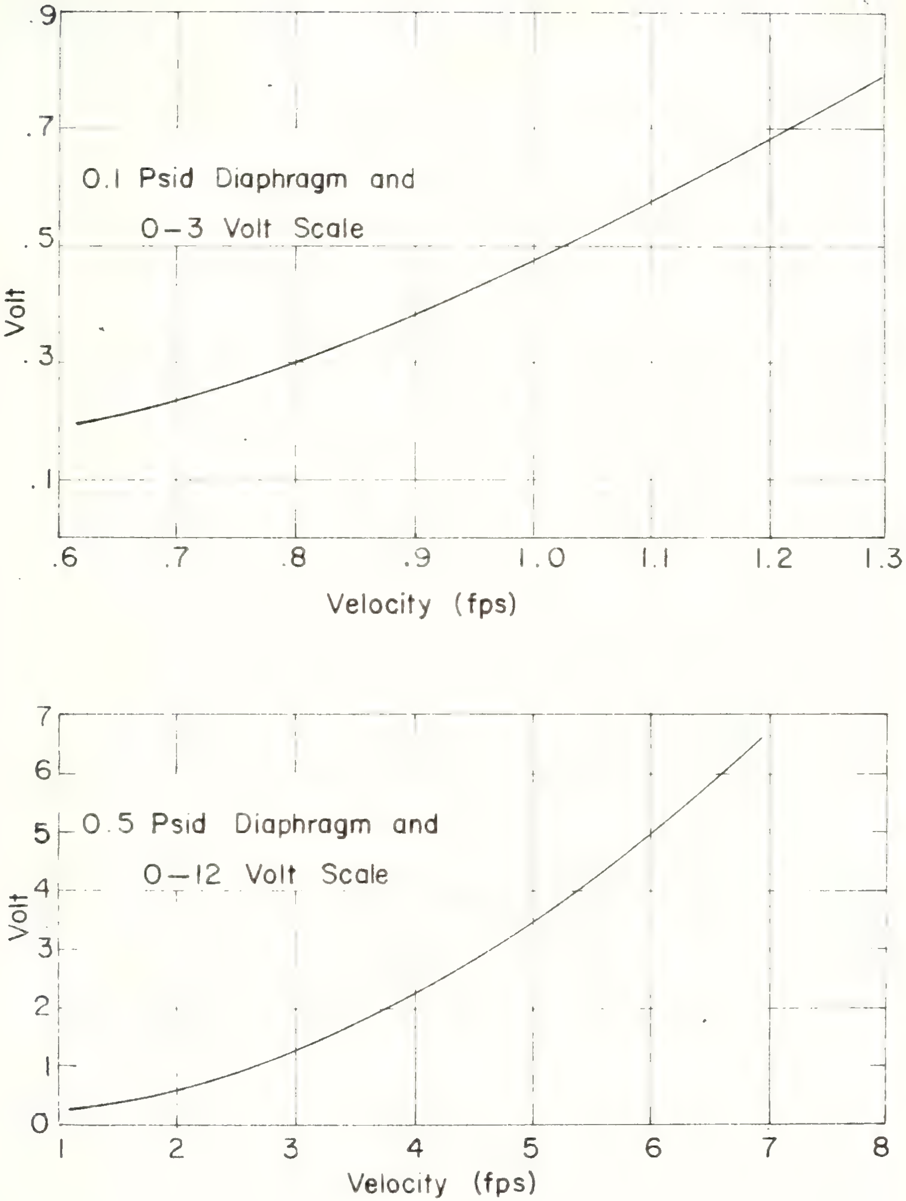


Fig. 5-12 Typical Calibration Curves for Probe

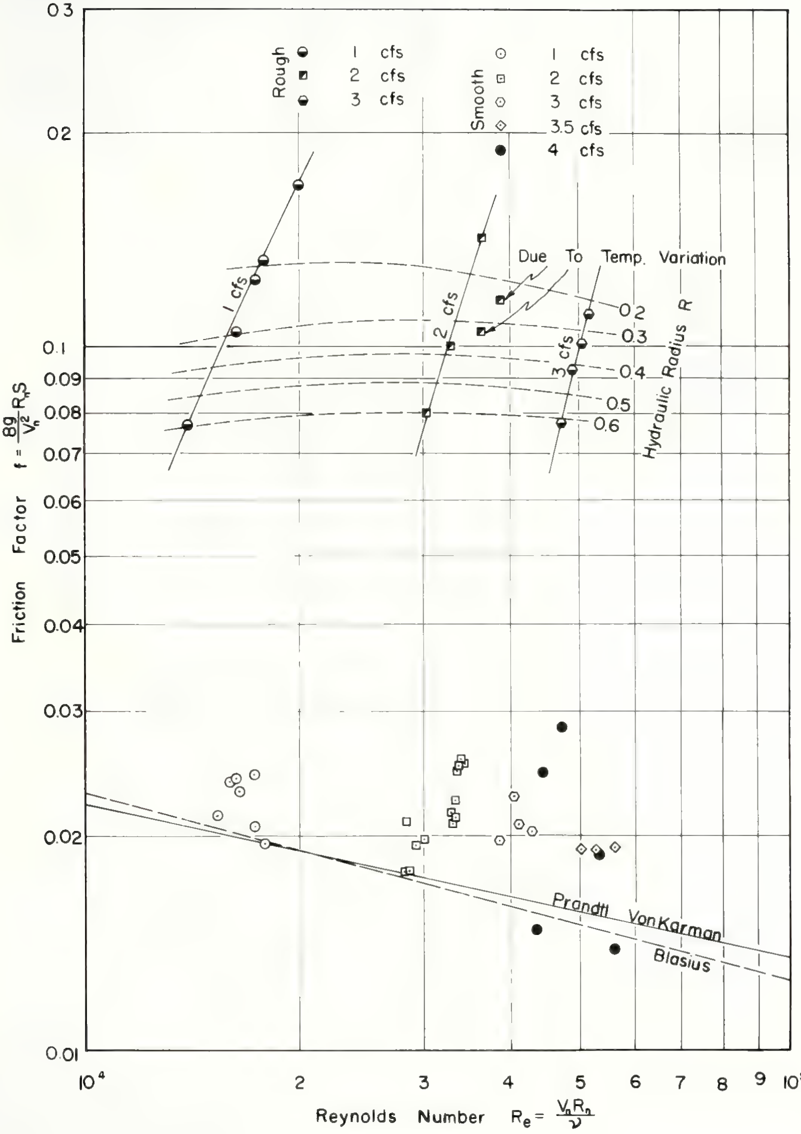


FIGURE 5-13 f – Re RELATION FOR NORMAL DEPTH TESTS

FIGURE 5-14 TESTING FLUME WITH ARTIFICIAL ROUGHNESS.

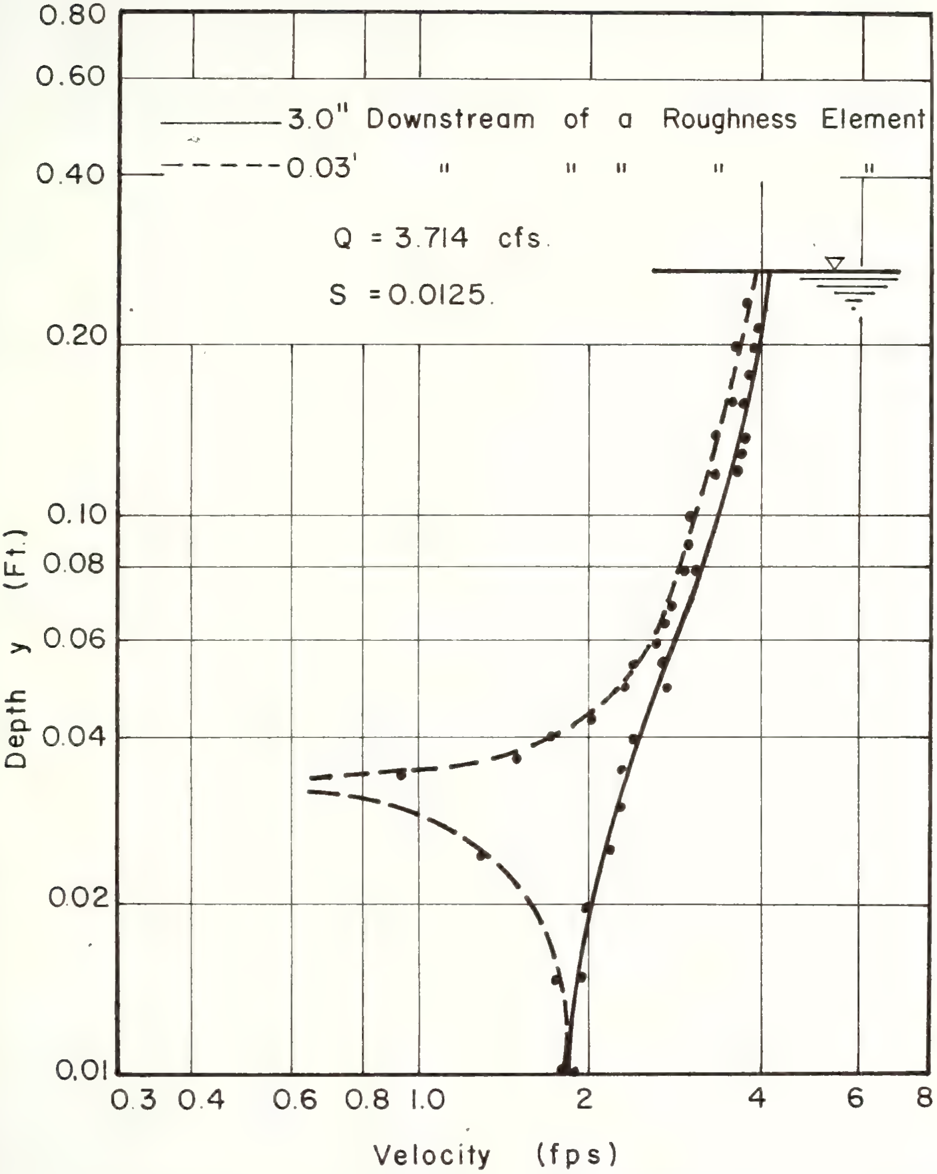


FIG 5-15 EFFECT OF BARS ON VELOCITY

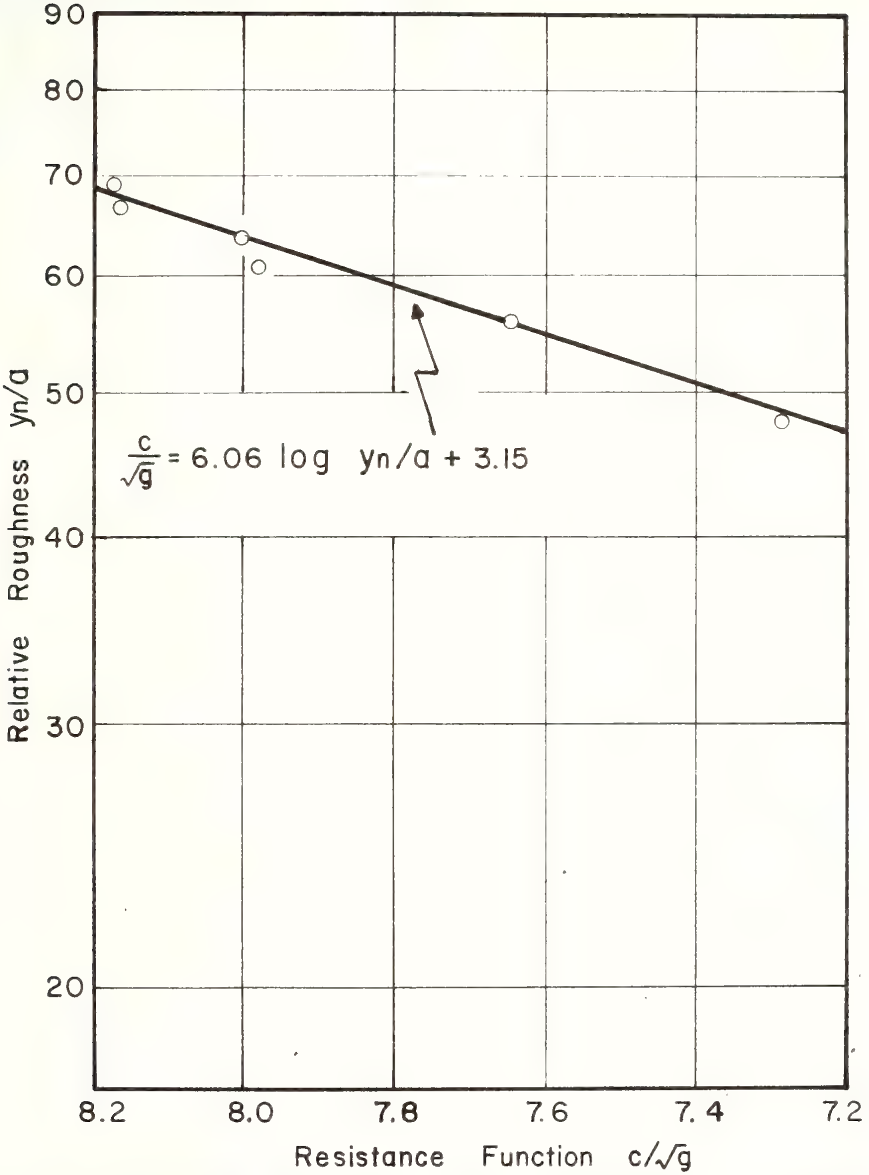


FIG 5-16 VARIATION OF RESISTANCE FUNCTION WITH RELATIVE ROUGHNESS yn/a

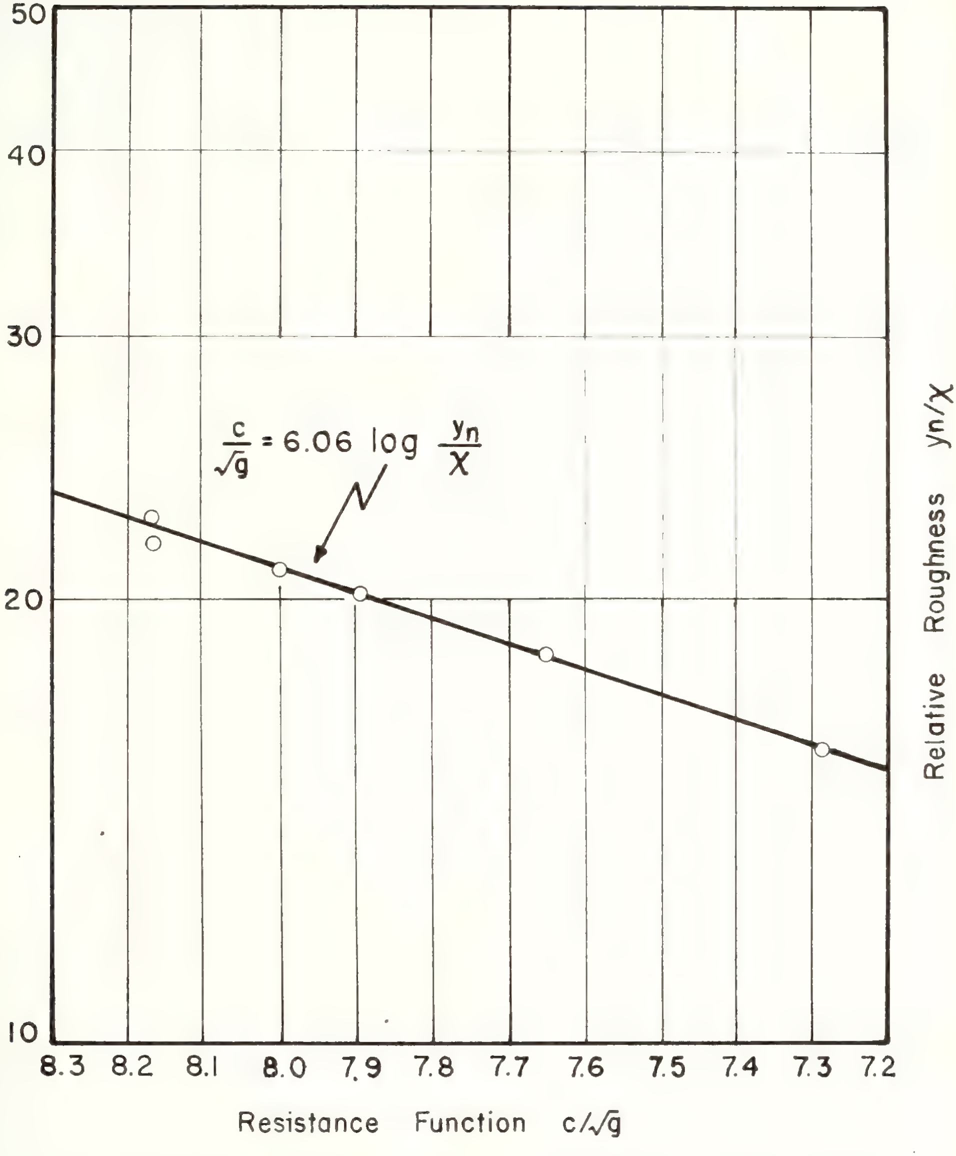


FIG 5-17 VARIATION OF RESISTANCE FUNCTION WITH RELATIVE ROUGHNESS y_n/χ

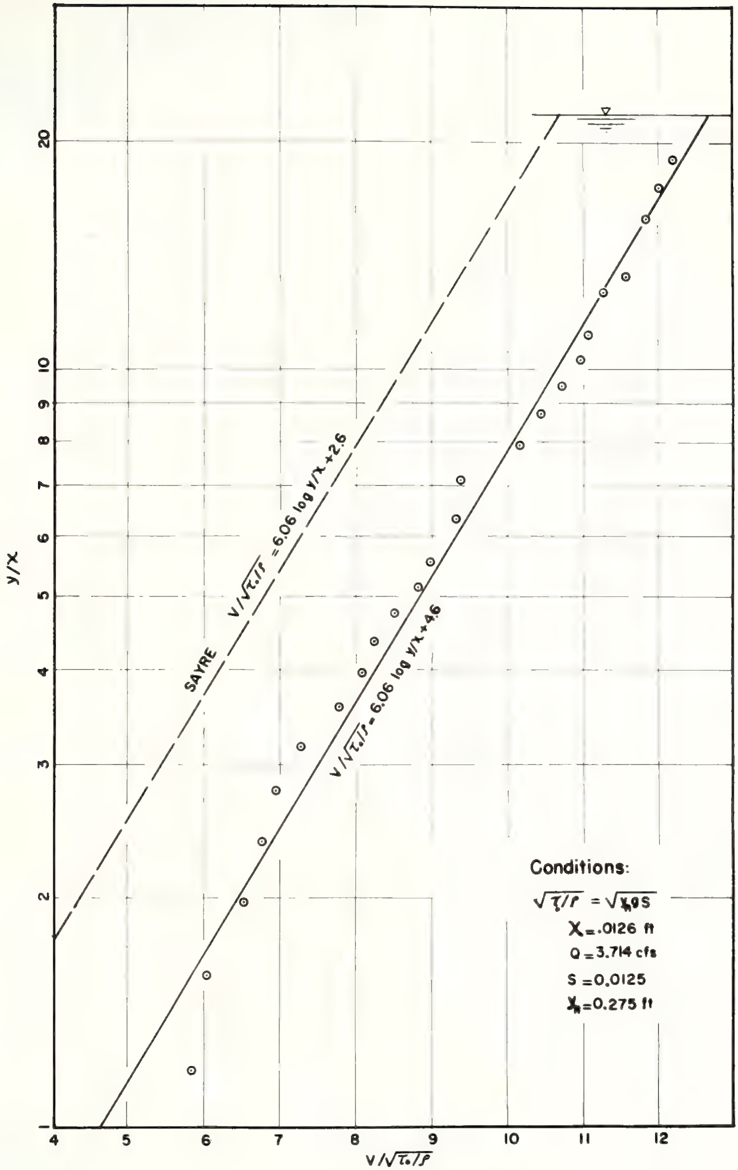


FIGURE 5-18 DIMENSIONLESS VELOCITY PROFILE

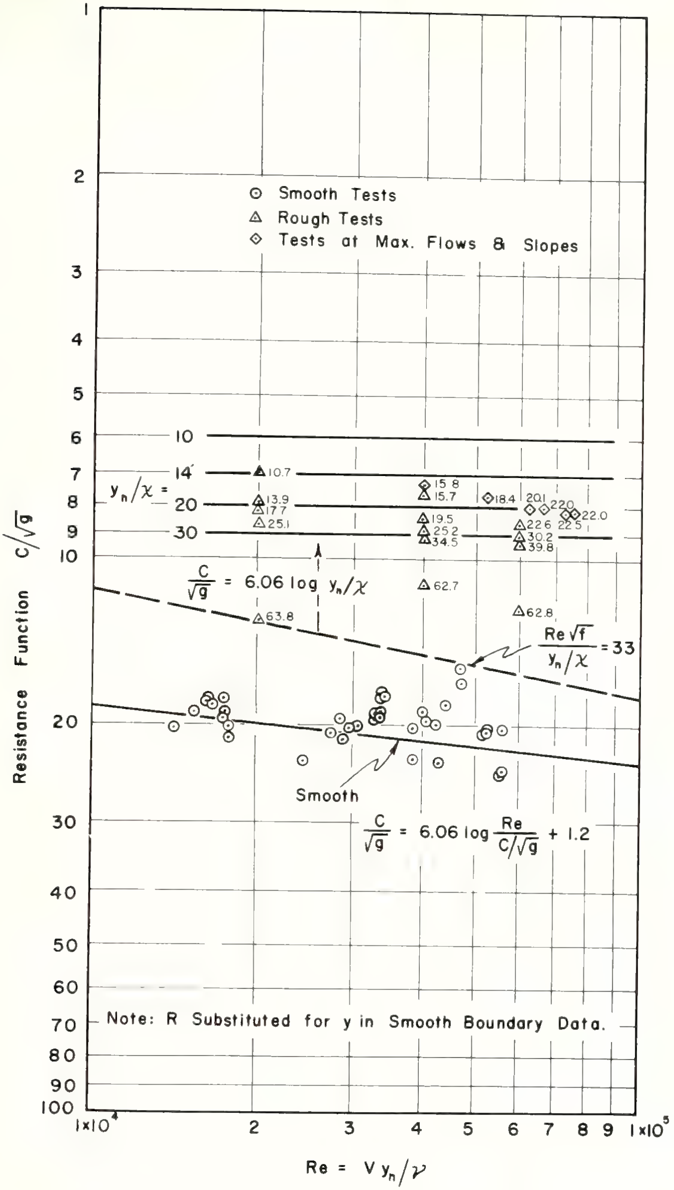


FIGURE 5-19 GENERAL RESISTANCE DIAGRAM FOR UNIFORM FLOW IN OPEN CHANNELS (SAYRE)

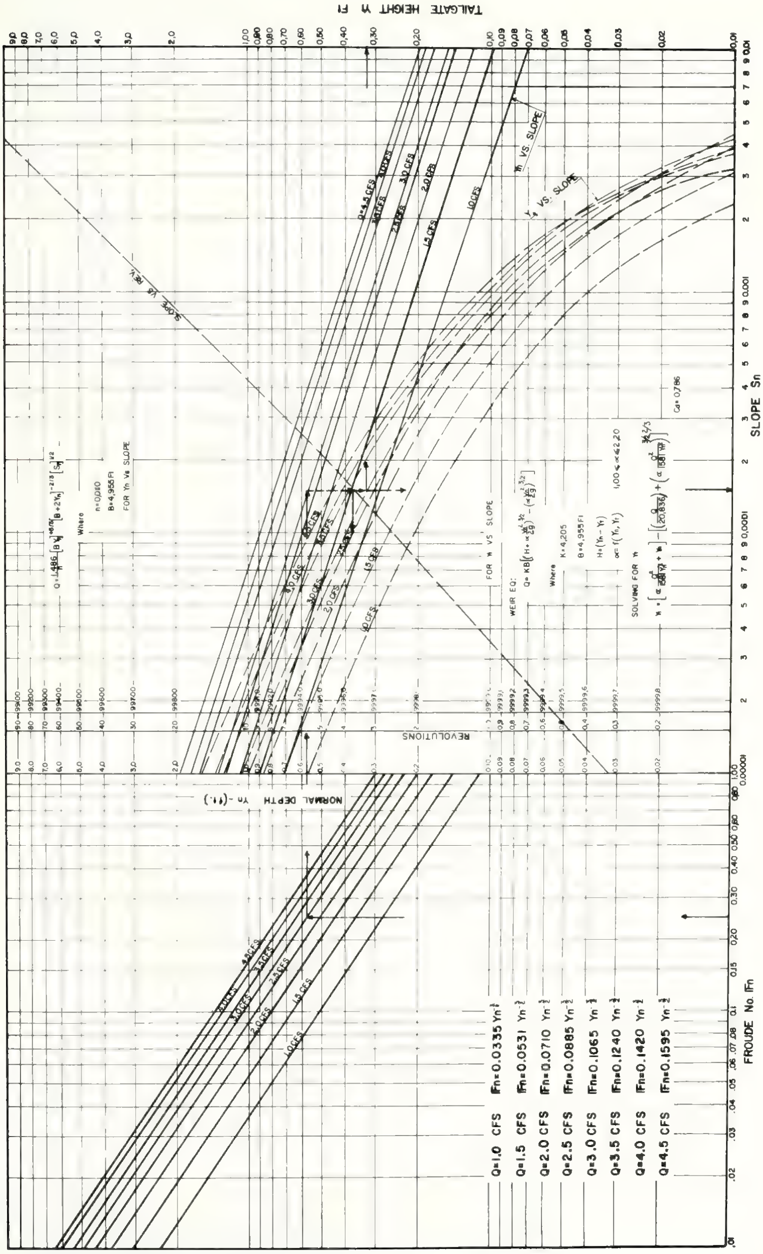


FIGURE 6-1 TESTS SELECTION CURVE — LARGE FLUME — SMOOTH BOUNDARIES

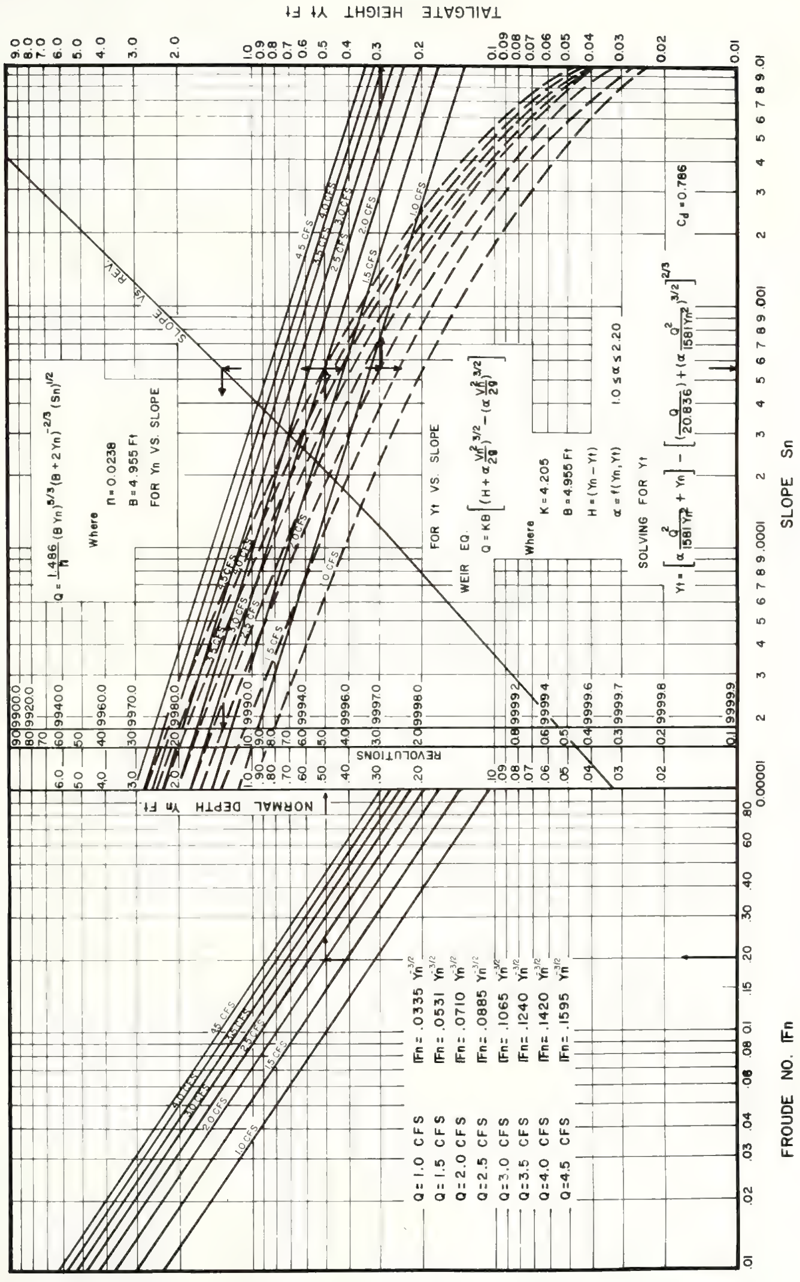


FIGURE 6-2 TESTS SELECTION CURVE — LARGE FLUME — ROUGH BOUNDARIES

PROGRAM FLOW CHART FOR DATA ANALYSIS

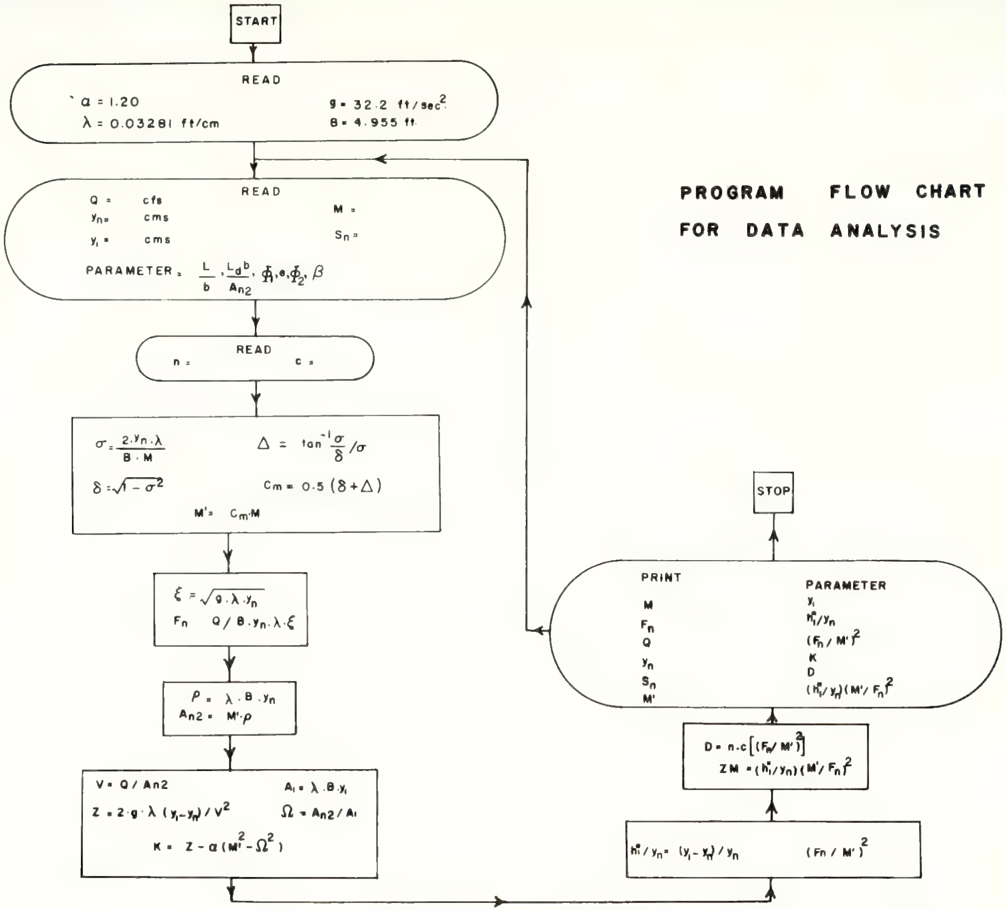
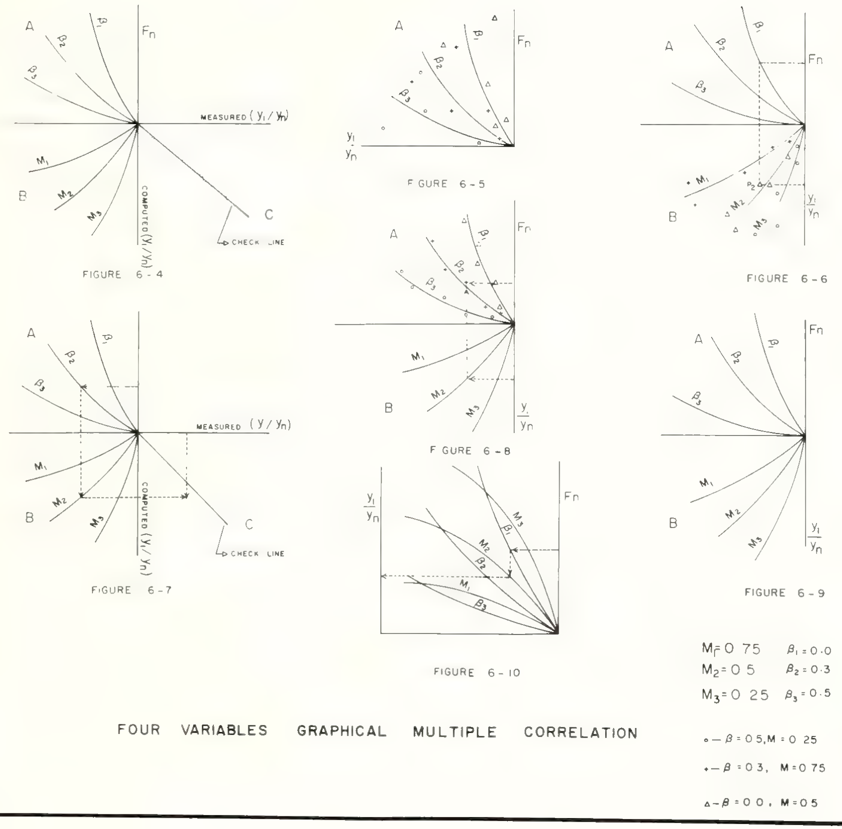


FIG. 6-3



FOUR VARIABLES GRAPHICAL MULTIPLE CORRELATION

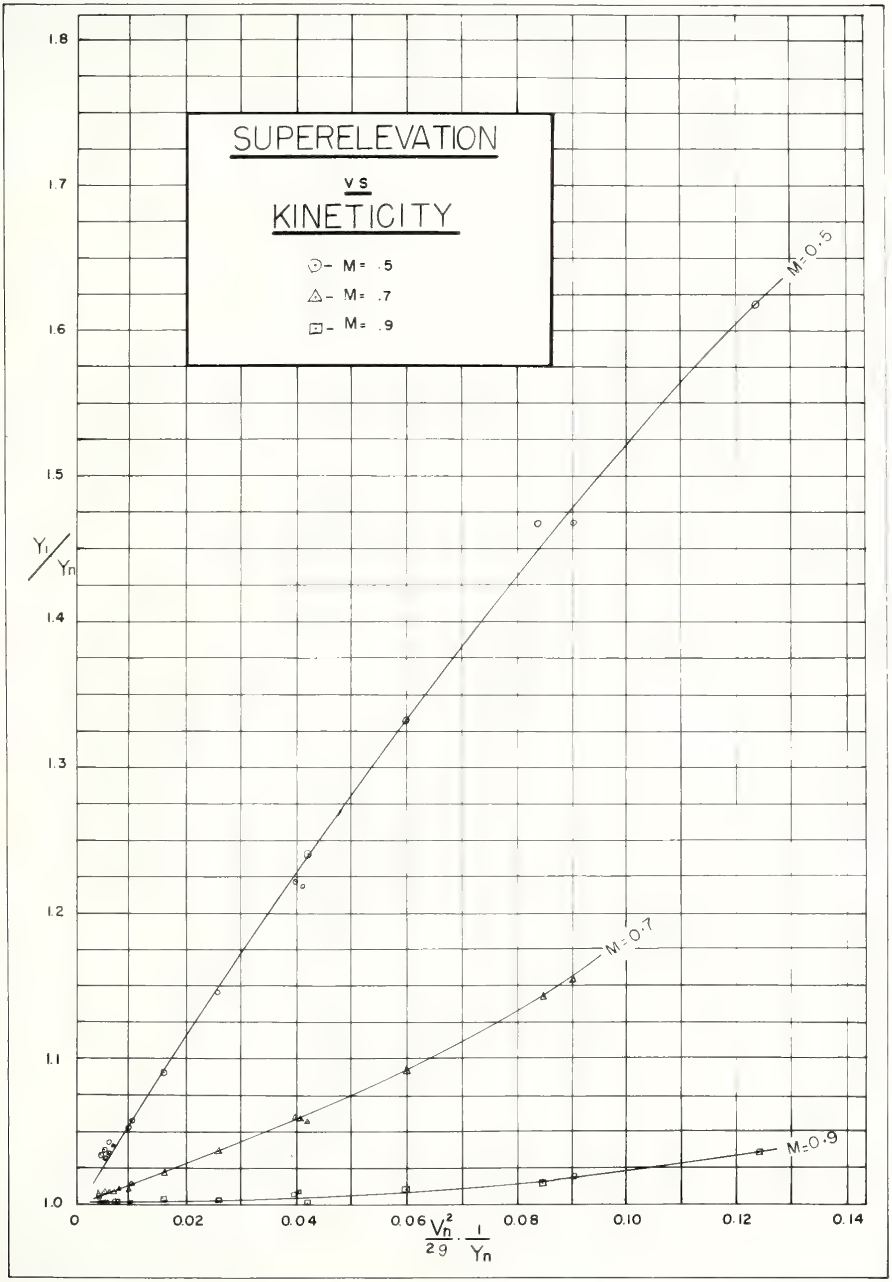

SUPERELEVATION
VS
KINETICITY
⊙ - M = .5
△ - M = .7
⊡ - M = .9
M=0.5
M=0.7
M=0.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
Y1/Yn
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
Vn²/2g · 1/Yn

FIGURE 7-1-1

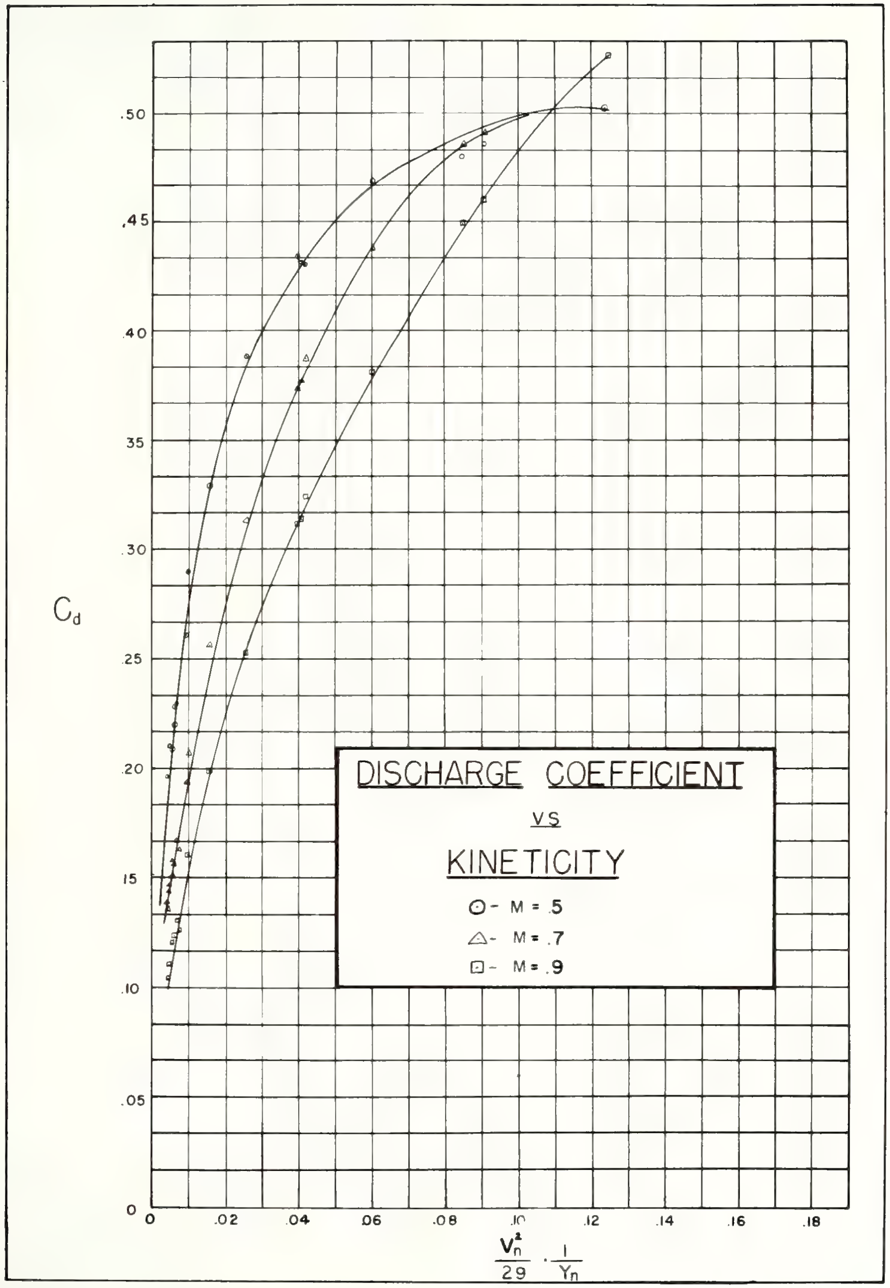

DISCHARGE COEFFICIENT
VS
KINETICITY
⊙ - M = .5
△ - M = .7
⊡ - M = .9
C_d
$\frac{V_n^2}{2g} \cdot \frac{1}{Y_n}$
0
.05
.10
.15
.20
.25
.30
.35
.40
.45
.50
0
.02
.04
.06
.08
.10
.12
.14
.16
.18

FIGURE 7-1-2

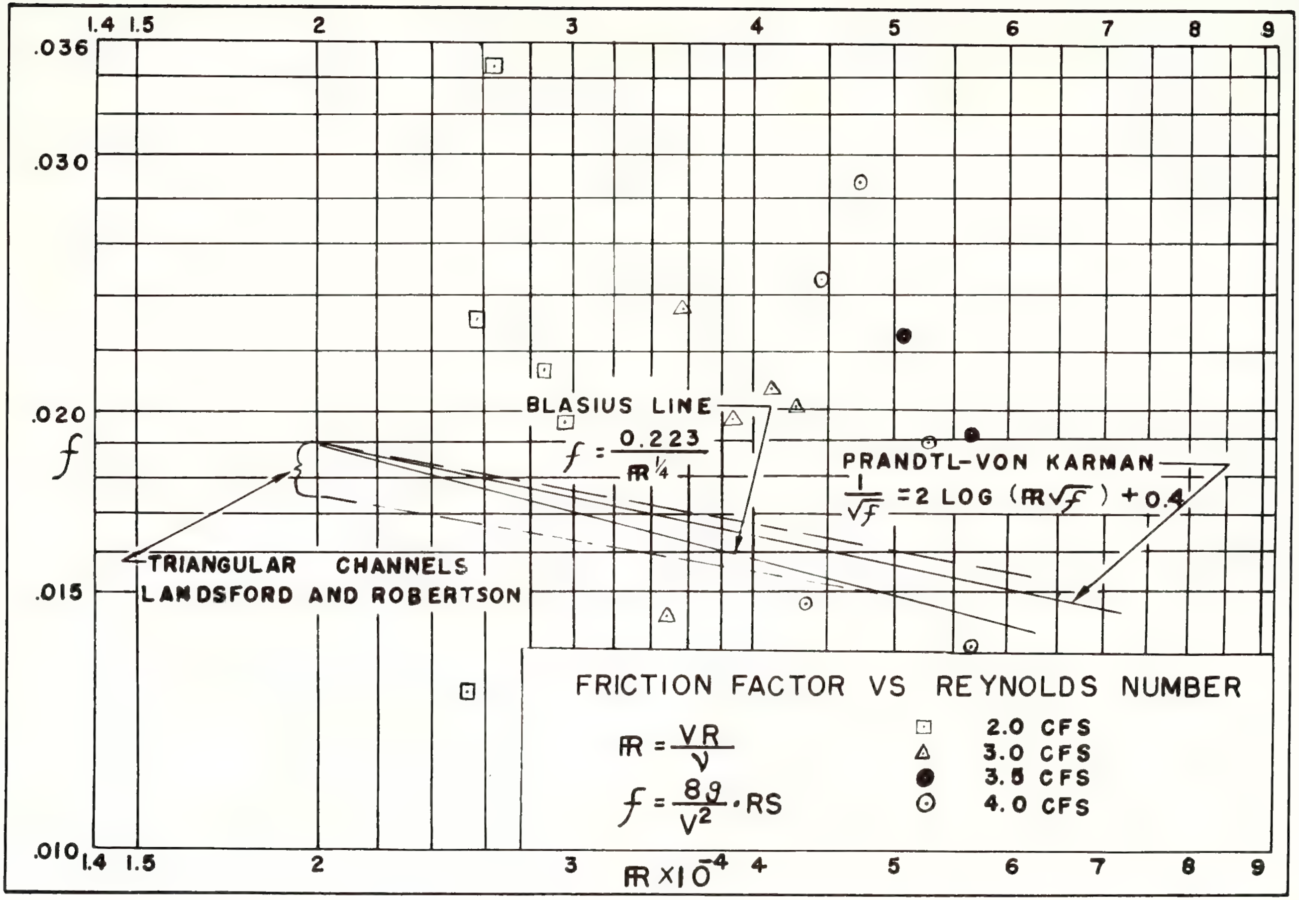
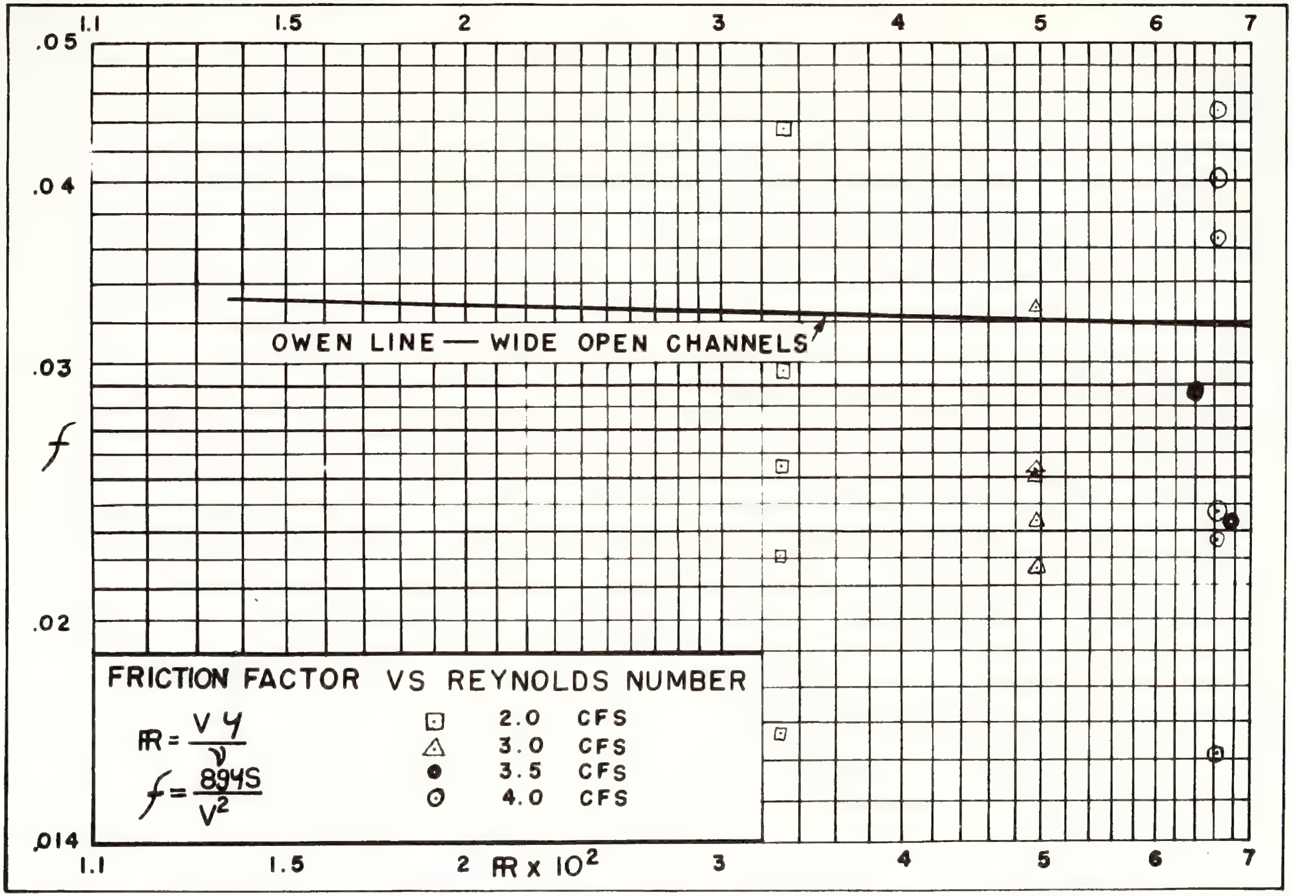
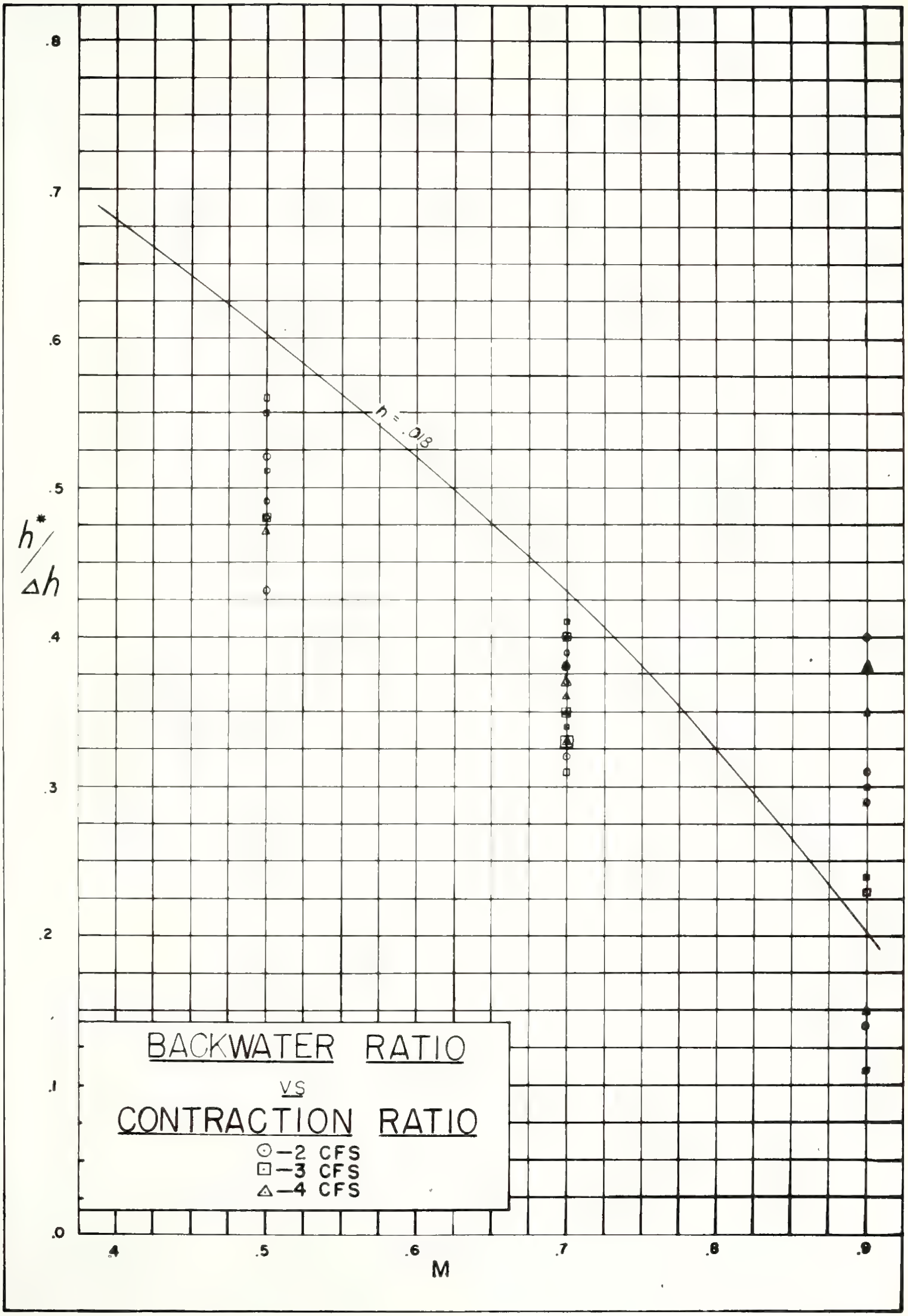

FRICTION FACTOR VS REYNOLDS NUMBER
$\mathbb{R} = \frac{VR}{\nu}$
$f = \frac{8g}{V^2} \cdot RS$
2.0 CFS
3.0 CFS
3.5 CFS
4.0 CFS
BLASIUS LINE
$f = \frac{0.223}{\mathbb{R}^{1/4}}$
PRANDTL-VON KARMAN
$\frac{1}{\sqrt{f}} = 2 \text{ LOG } (\mathbb{R}\sqrt{f}) + 0.4$
TRIANGULAR CHANNELS
LAMDSFORD AND ROBERTSON
f
.036
.030
.020
.015
.010
1.4
1.5
2
3
4
5
6
7
8
9
$\mathbb{R} \times 10^{-4}$

FIGURE 7-1-3



1.1
1.5
2
3
4
5
6
7
.05
.04
.03
.02
.014
f
OWEN LINE — WIDE OPEN CHANNELS
FRICTION FACTOR VS REYNOLDS NUMBER
R = Vy/ν
f = 894S/V²
2.0 CFS
3.0 CFS
3.5 CFS
4.0 CFS
R x 10²

FIGURE 7-1-4



BACKWATER RATIO
VS
CONTRACTION RATIO
⊙—2 CFS
⊡—3 CFS
△—4 CFS
n = .018
$h^*/\Delta h$
M
.0
.1
.2
.3
.4
.5
.6
.7
.8
.4
.5
.6
.7
.8
.9

FIGURE 7-1-5

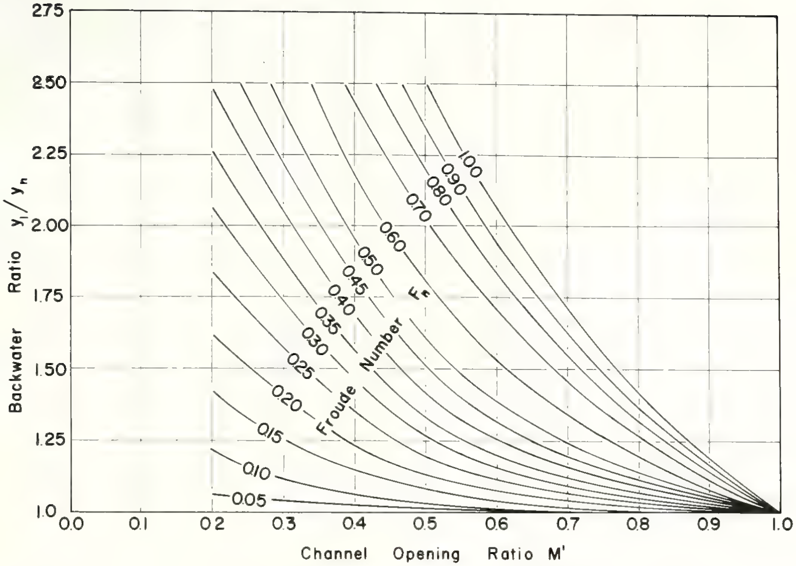


FIGURE 7-1-6 — BACKWATER RATIO VS CHANNEL OPENING RATIO L/b =0 SEMI-CIRC. SMOOTH CHANNEL

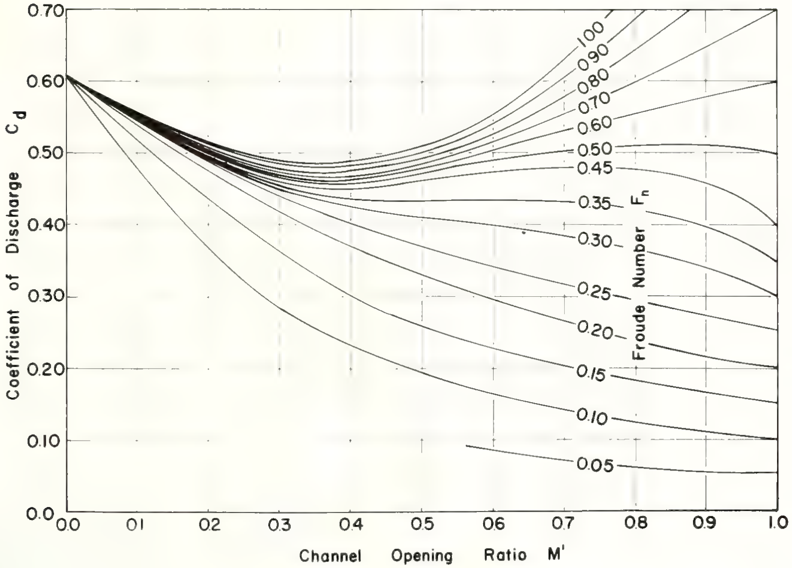


FIGURE 7-1-7 DISCHARGE COEF. VS CHANNEL OPENING RATIO L/b =0 SEMI-CIRC. SMOOTH CHANNEL

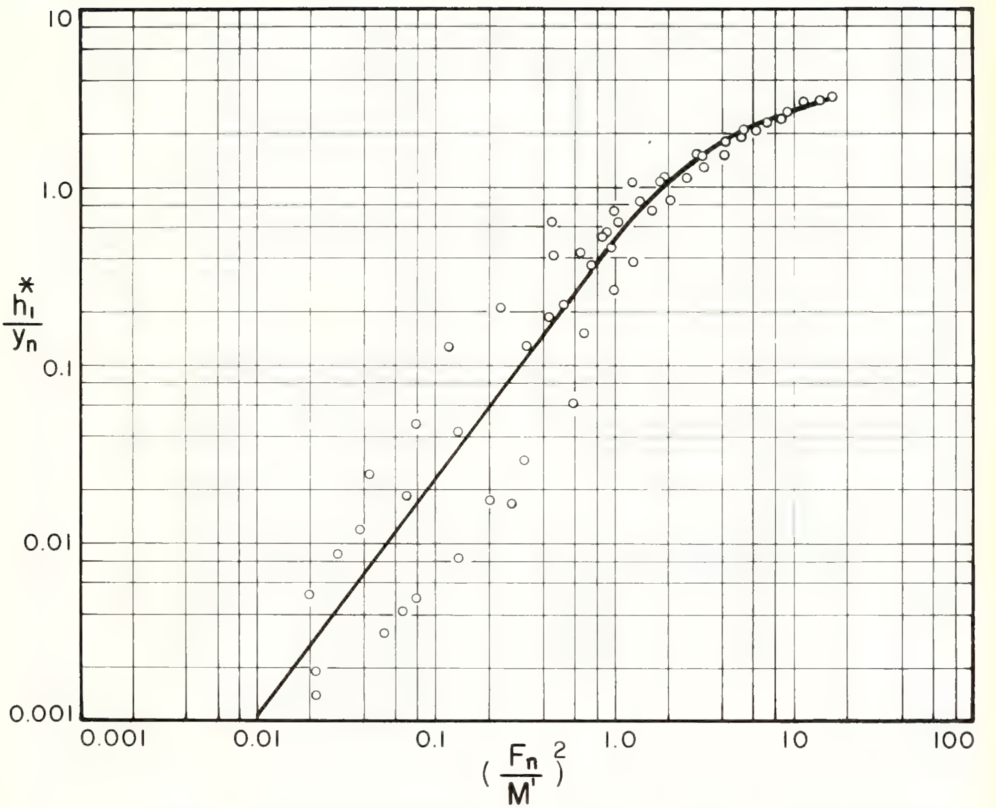


FIGURE 7-1-8 BACKWATER RATIO FOR GEOMETRY I_a, SMOOTH BOUNDARY $\frac{L}{b}$ = 0.0

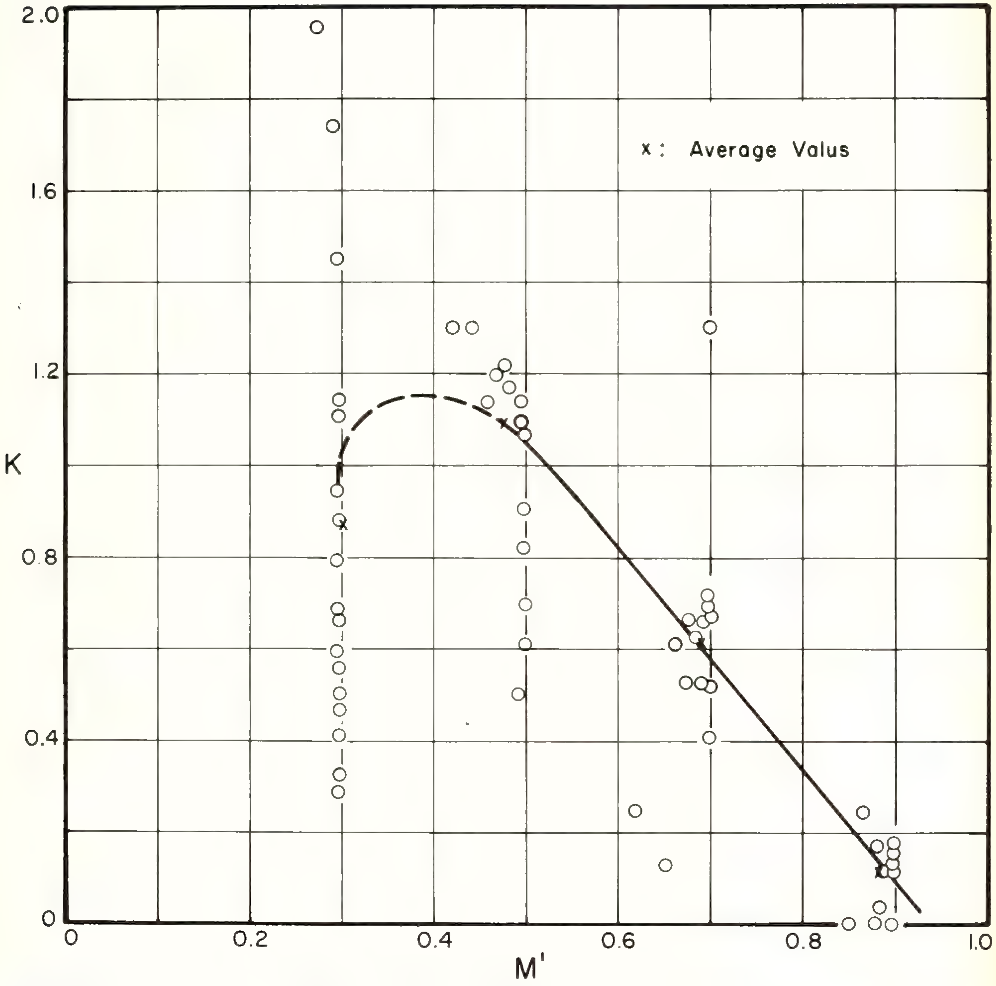


FIGURE 7-1-9 HEAD LOSS COEFFICIENT, GEOMETRY I_a

SMOOTH BOUNDARY $\frac{L}{b} = 0.0$

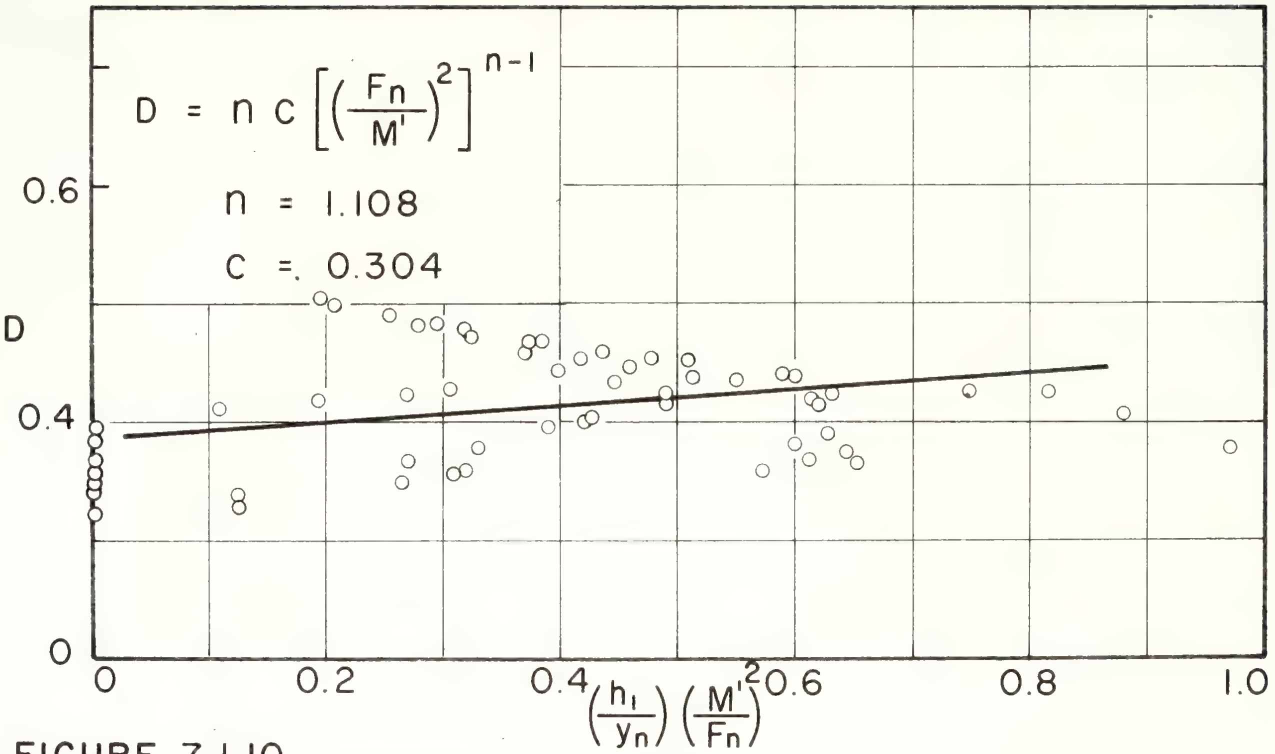


FIGURE 7-1-10 BACKWATER RATIO COEFFICIENT, GEOMETRY I_a, SMOOTH BOUNDARY $\frac{L}{b} = 0.0$

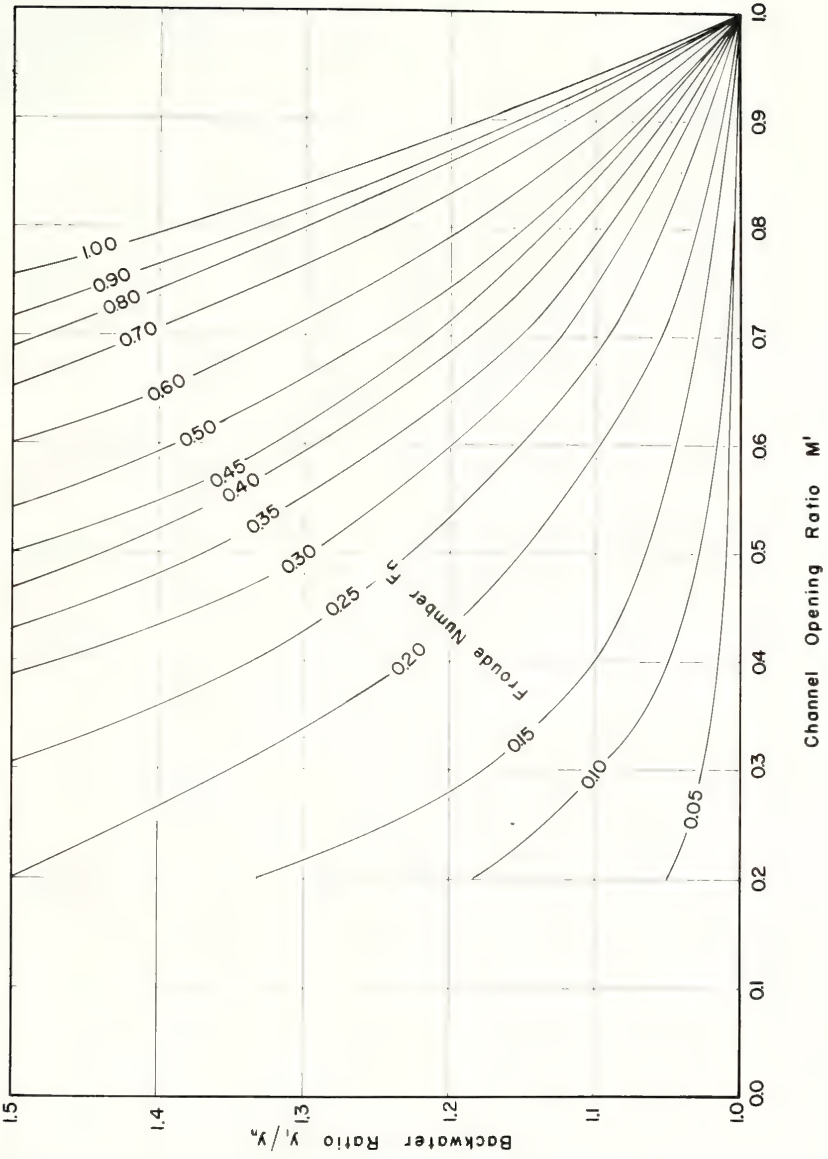


FIGURE 7-2-1a BACKWATER RATIO VS CHANNEL OPENING RATIO L/b=0 SEMI-CIRC. ROUGH CHANNEL $y_1/y_n \leq 1.50$

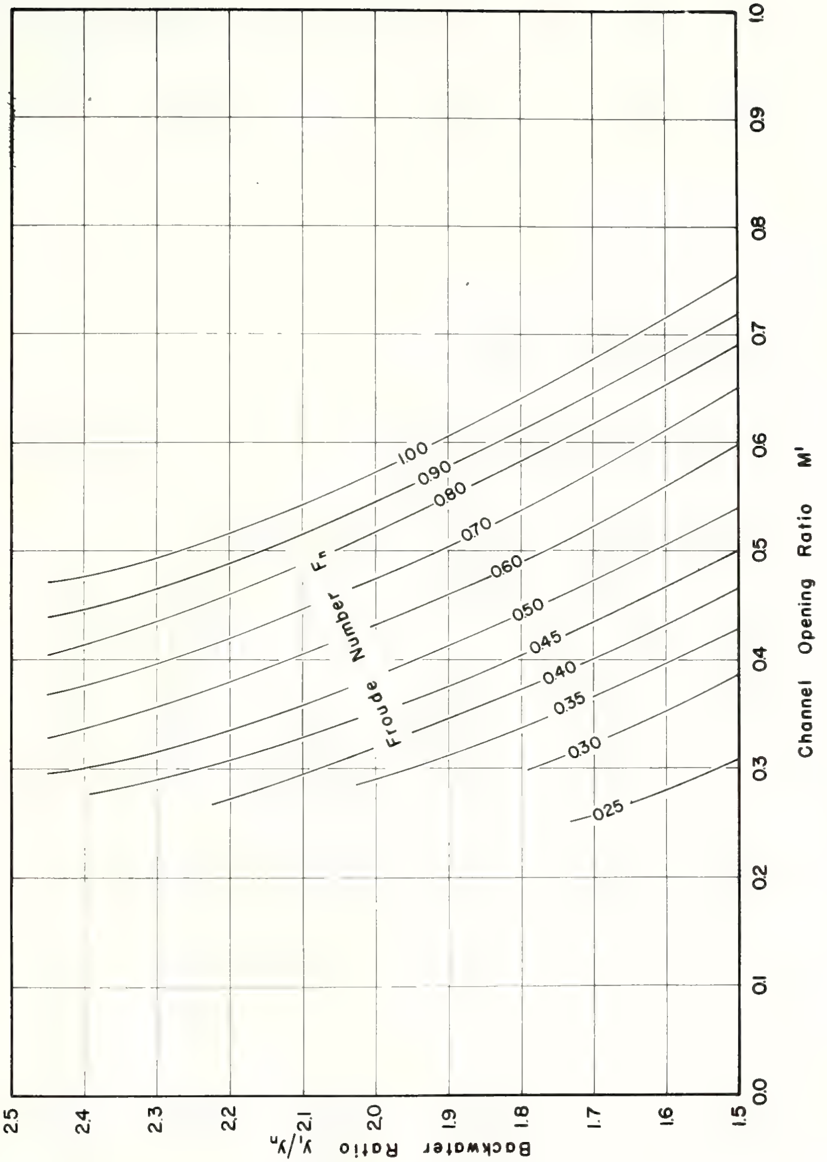


FIGURE 7-2-1b BACKWATER RATIO VS CHANNEL OPENING RATIO L/b=0 SEMI-CIRC. ROUGH CHANNEL $1.50 \leq y_1/y_n \leq 2.50$

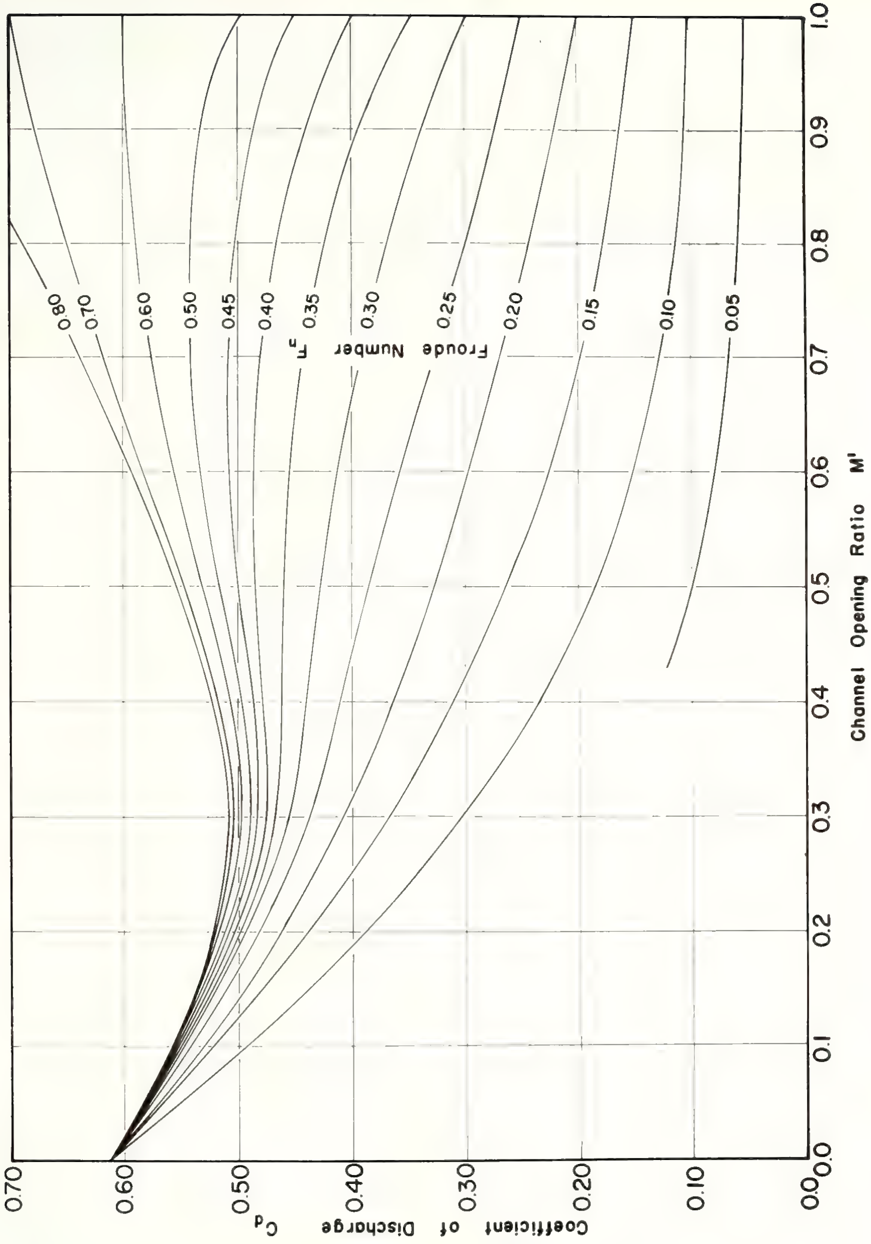


FIGURE 7-2-2 DISCHARGE COEF. VS CHANNEL OPENING RATIO L/b =0 SEMI-CIRC. ROUGH CHANNEL

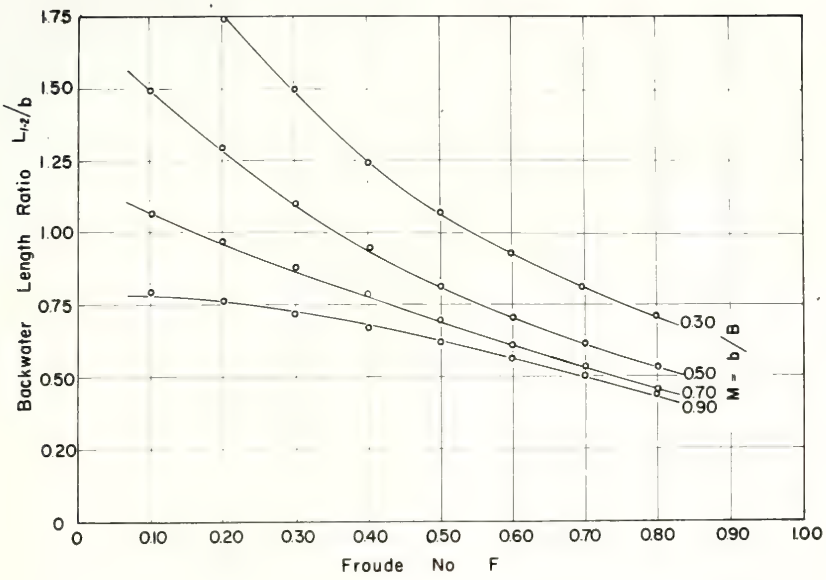


FIGURE 7-2-3a LENGTH TO MAXIMUM BACKWATER

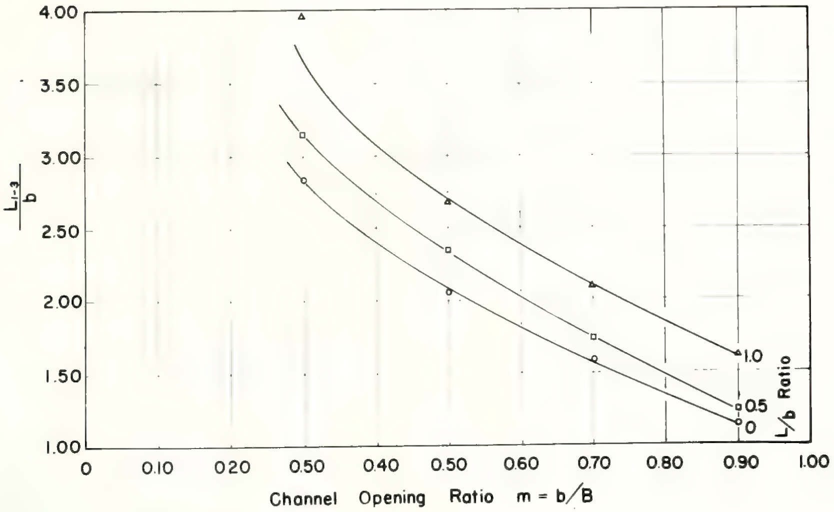


FIGURE 7-2-3b LENGTH OF SURFACE PROFILE BETWEEN y_1 & y_3

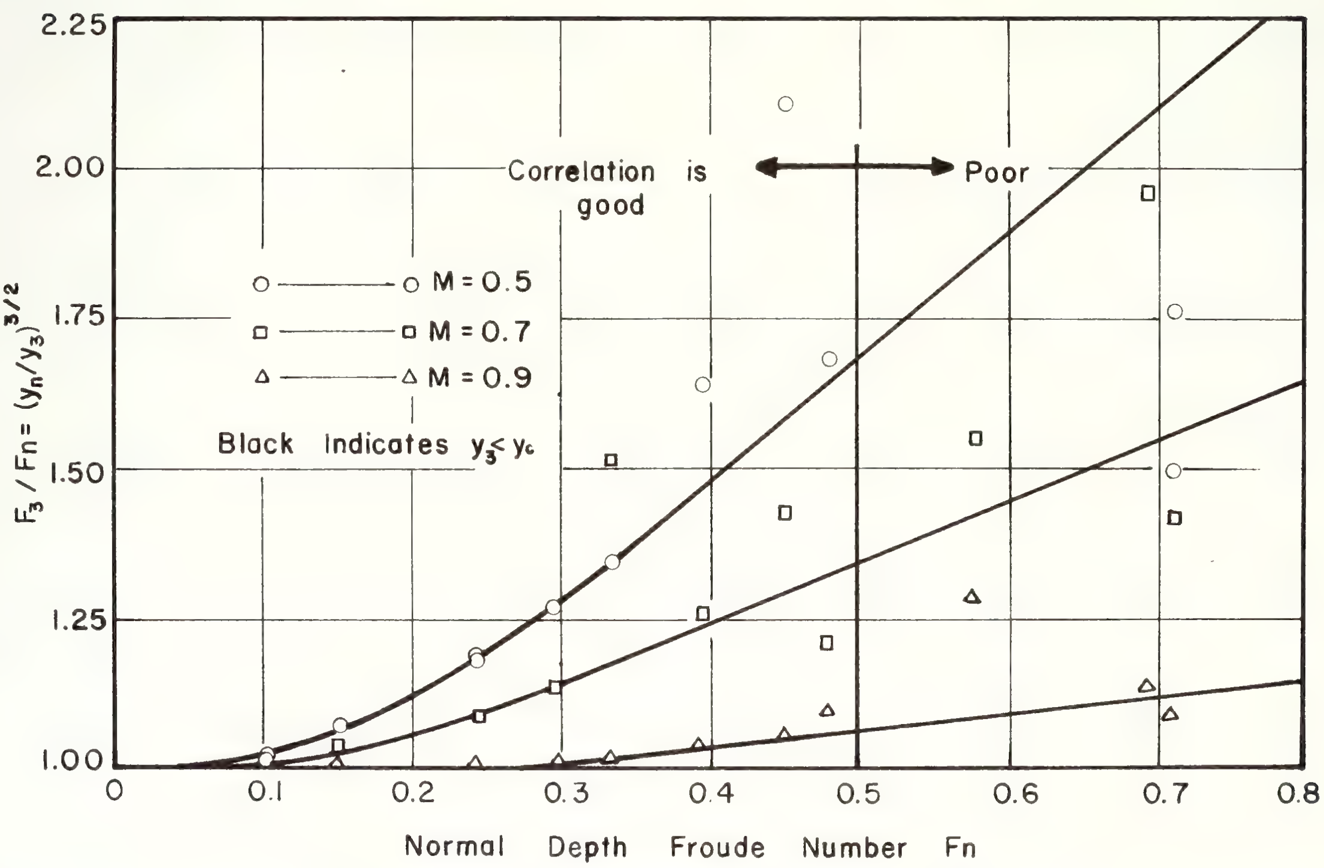


FIG 7-2-4 CORRELATION CURVE OF F_3

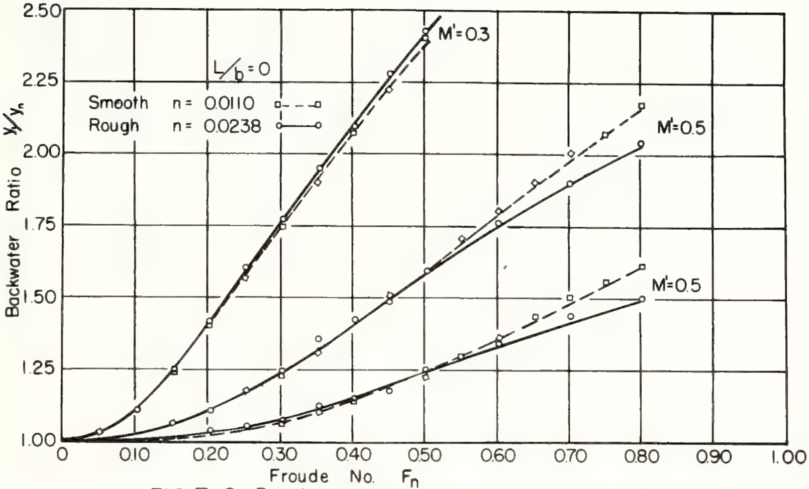


FIG. 7-2-5a COMPARISON BETWEEN BACKWATER RATIOS IN SMOOTH AND ROUGH CHANNELS

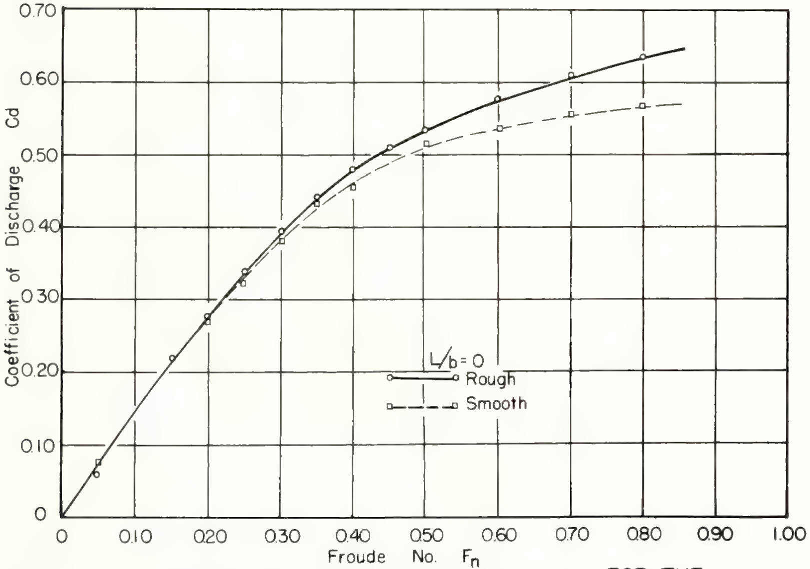


FIG. 7-2-5b COMPARISON OF Cd TO F_n FOR THE TWO ROUGHNESS CONDITIONS M'=0.7

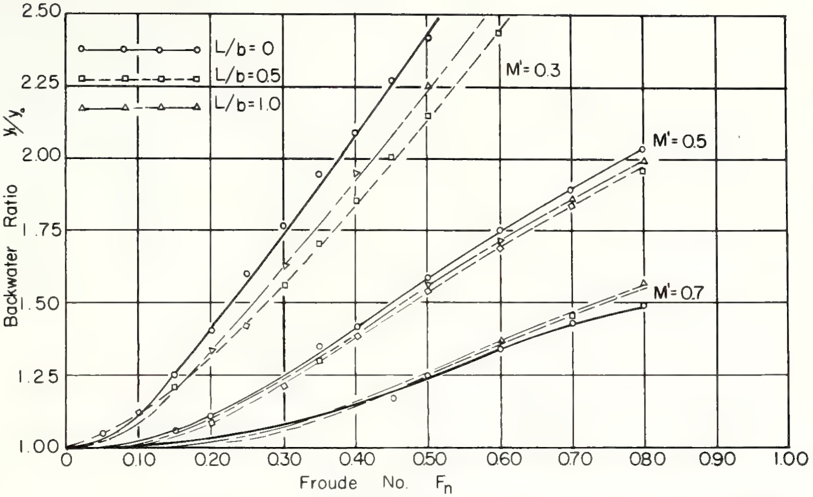


FIG. 7-2-6a COMPARISON BETWEEN BACKWATER RATIOS FOR BRIDGE LENGTHS - ROUGH CHANNEL

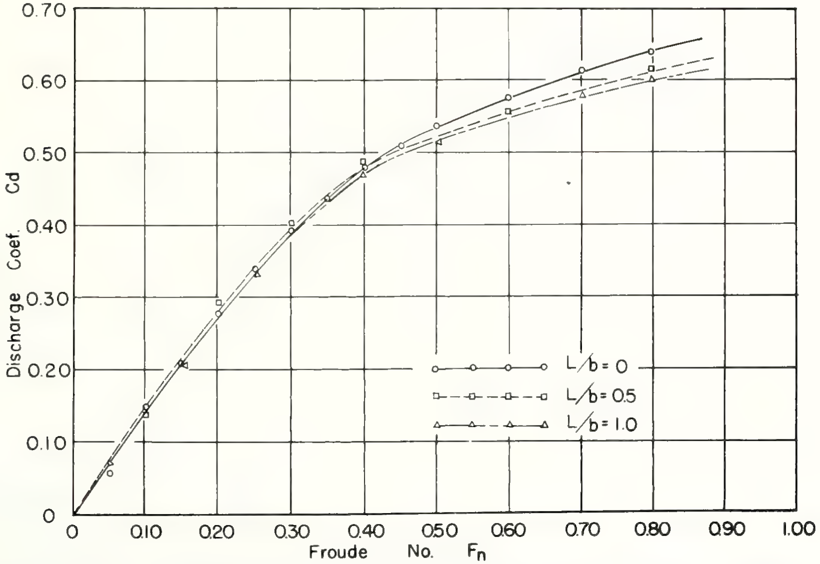


FIG. 7-2-6b COMPARISON BETWEEN DISCHARGE COEFFICIENTS FOR BRIDGE LENGTHS - ROUGH CHANNEL - M' = 0.7

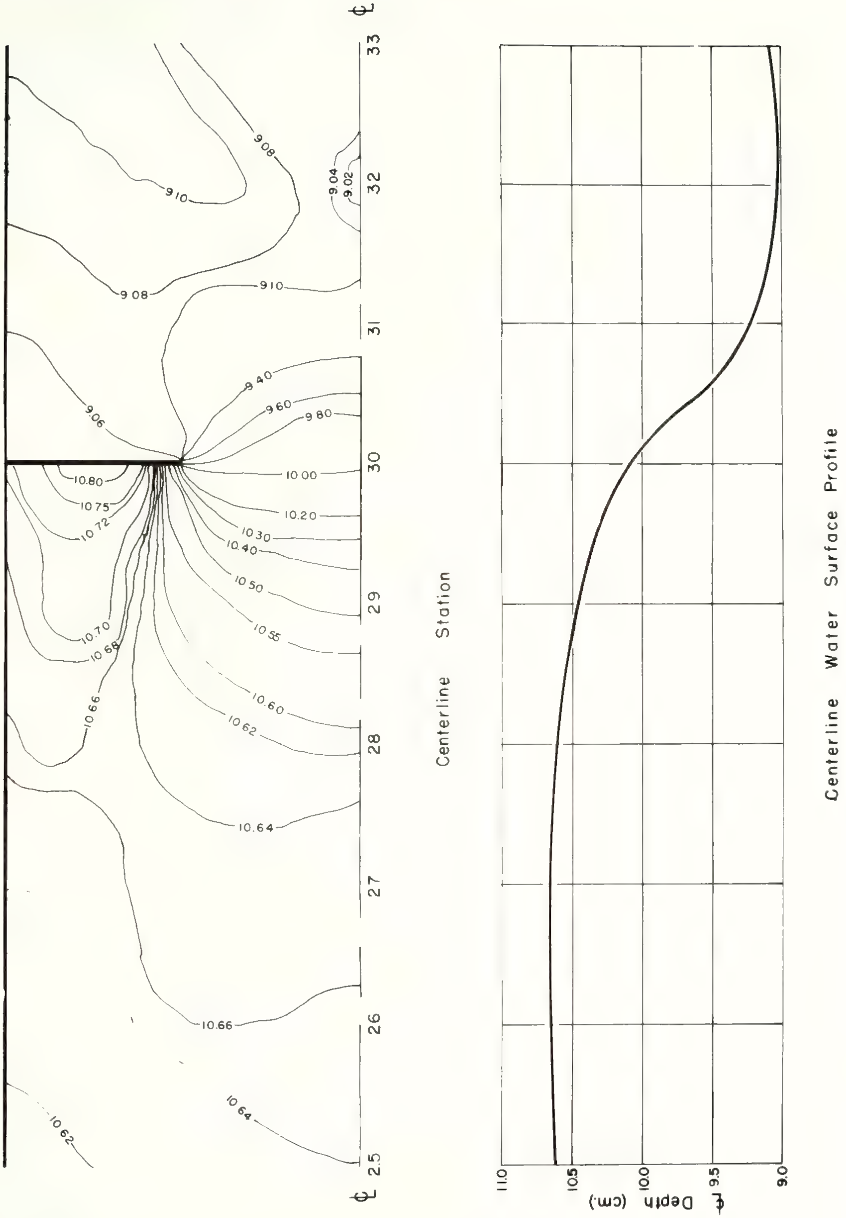


FIGURE 7-2-7 SURFACE TOPOGRAPHY Q = 1 CFS, S= 0.000584, M = 0.5, L/b=0

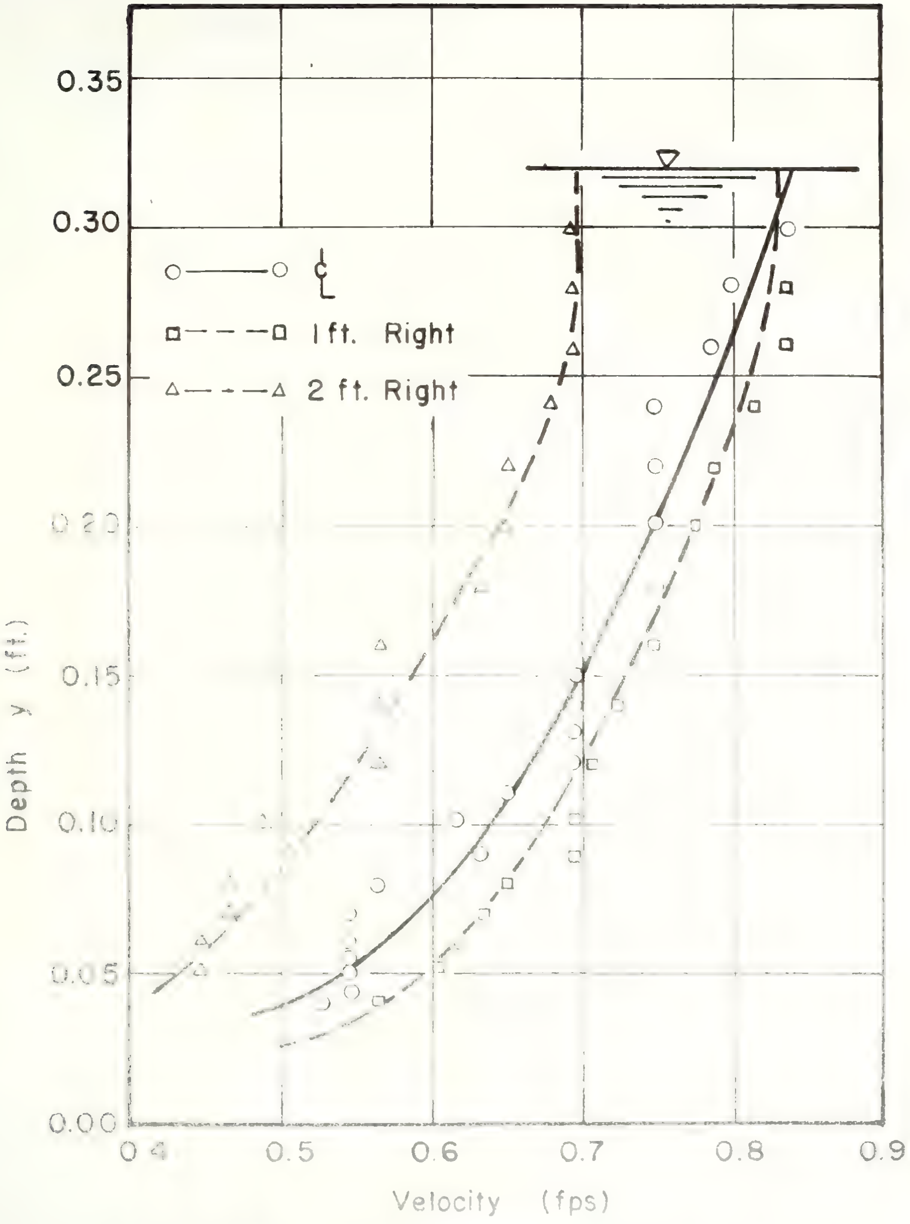


FIG. [illegible] 2-6 VELOCITY PROFILES AT MAXIMUM BACKWATER, Q = 1 CFS, S = [illegible], M = 0.5, L/b = [illegible]

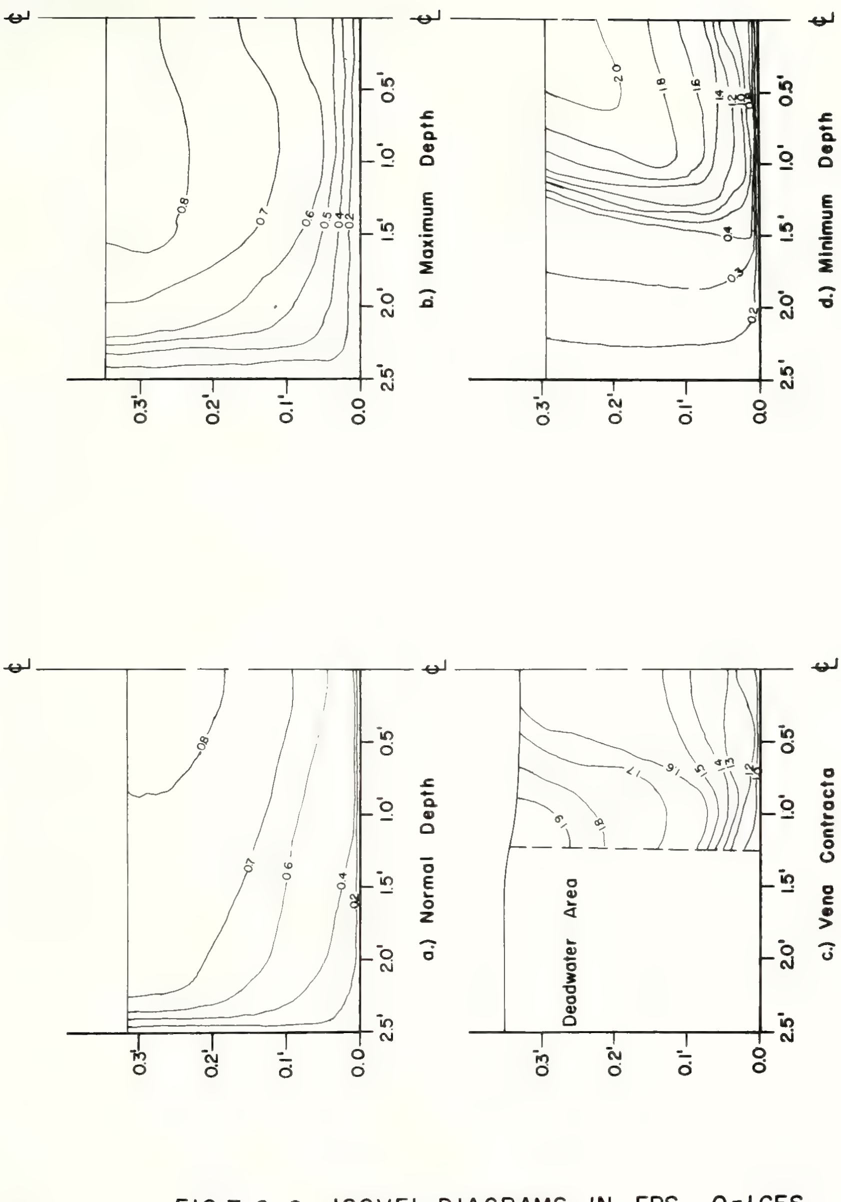


FIG. 7-2-9 ISOVEL DIAGRAMS IN FPS Q=1CFS,
S=0.000584, M=0.5, L/b=0

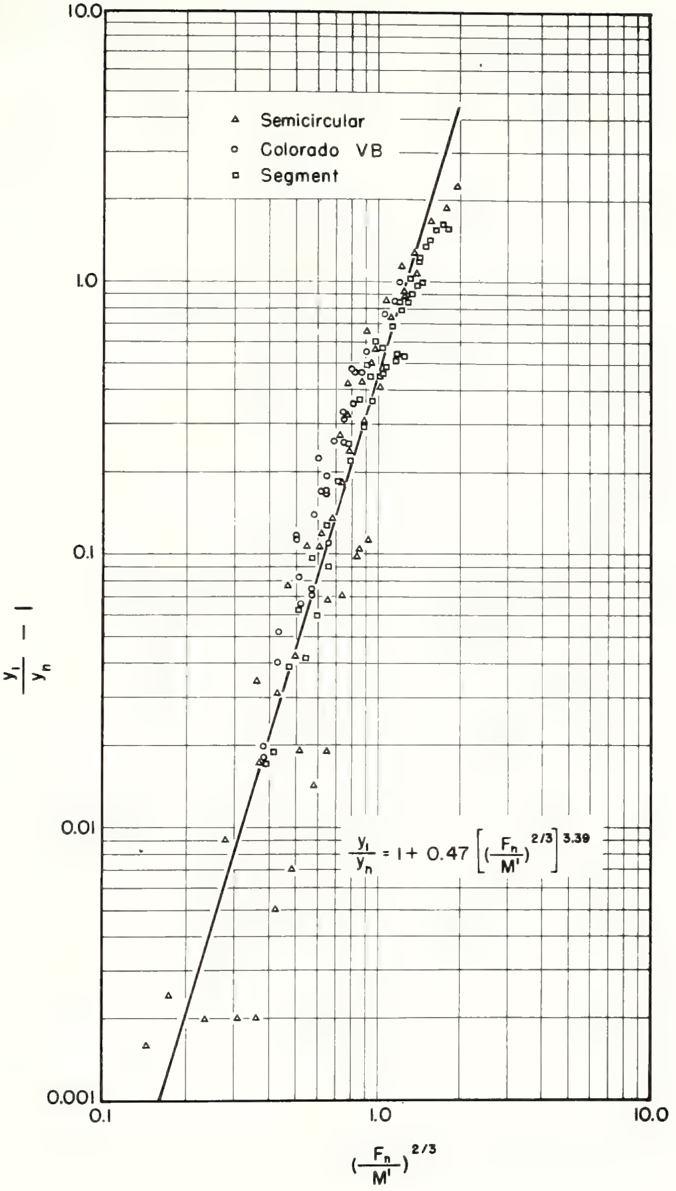


FIGURE 7-2-10 GENERALIZED BACKWATER RATIO

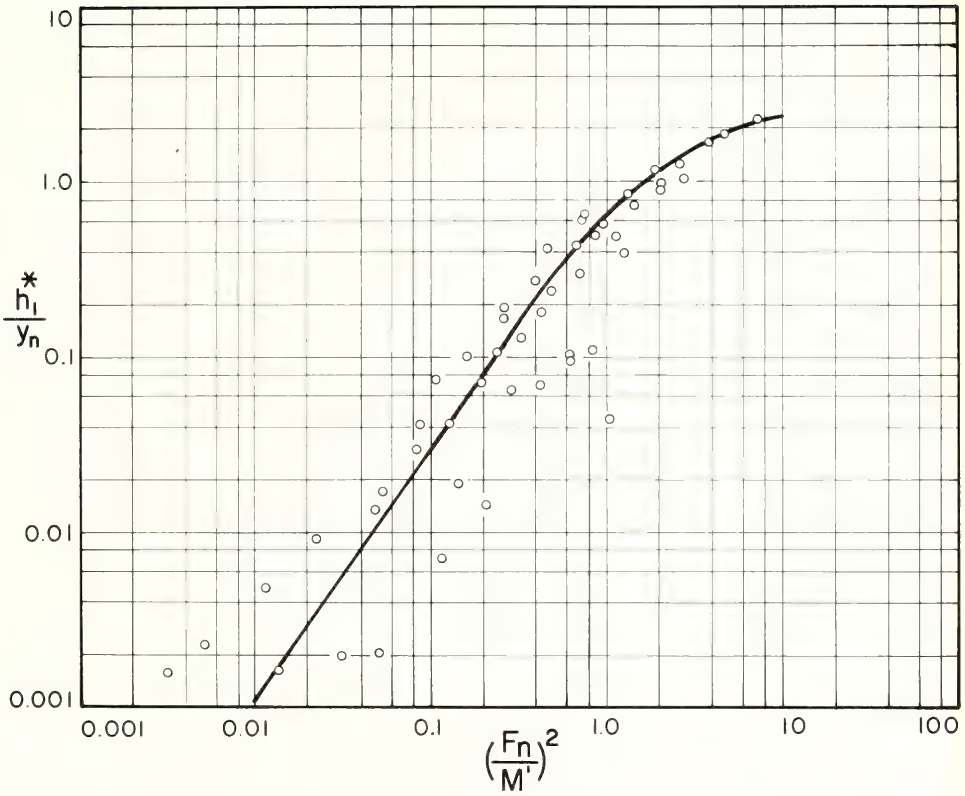


FIGURE 7-2-11 BACKWATER RATIO FOR GEOMETRY I_a, ROUGH BOUNDARY $\frac{L}{b}$ = 0.0

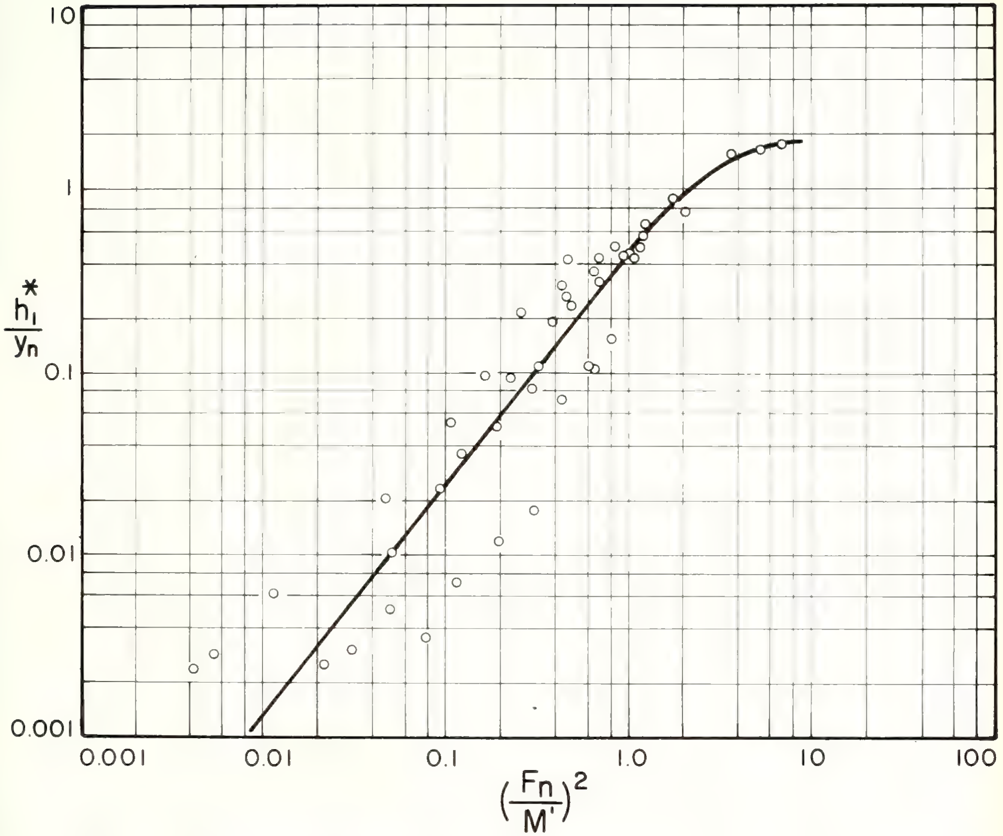


FIGURE 7-2-12 BACKWATER RATIO FOR GEOMETRY I_b, ROUGH BOUNDARY $\frac{L}{b} = 0.5$

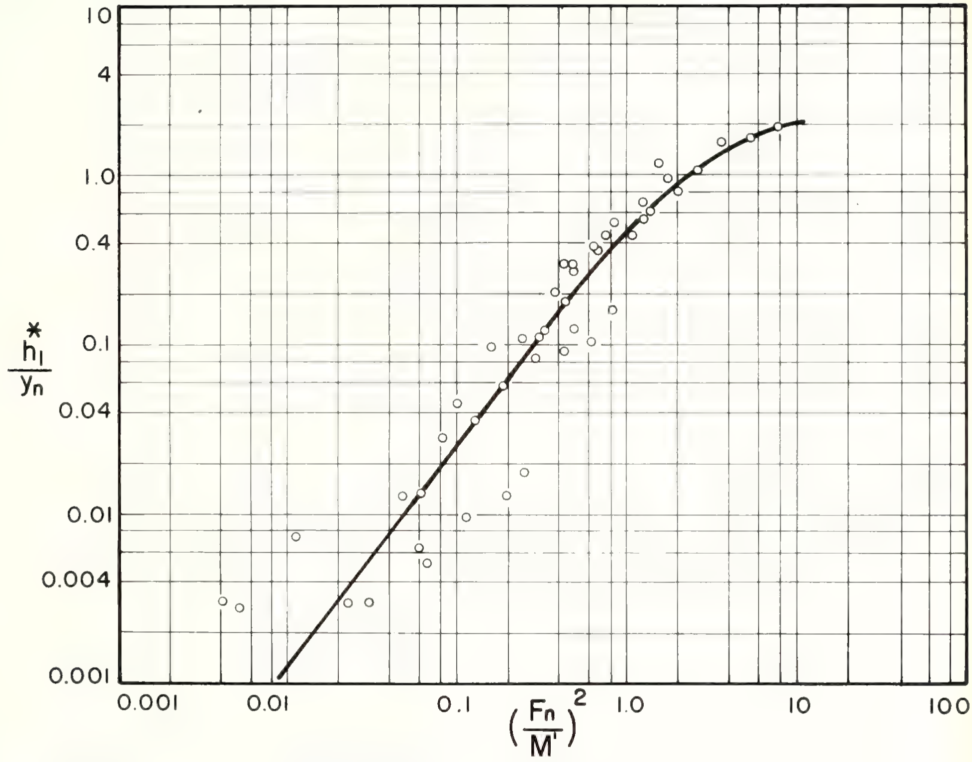


FIGURE 7-2-13 BACKWATER RATIO FOR GEOMETRY I_b ROUGH BOUNDARY $\frac{L}{b} = 1.0$

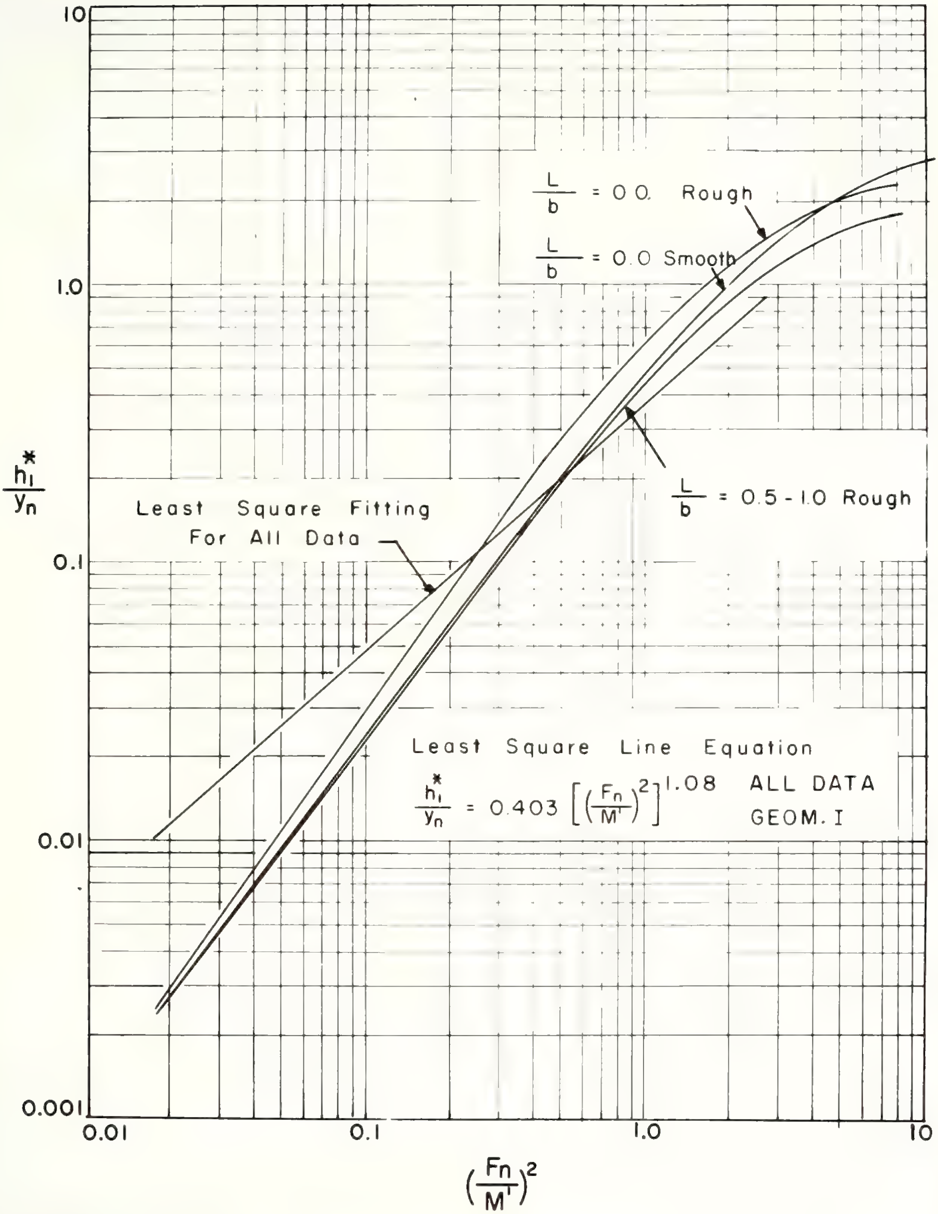


FIGURE 7-2-14 SUMMARY OF BACKWATER RATIO, GEOMETRY I, ROUGH & SMOOTH BOUNDARIES

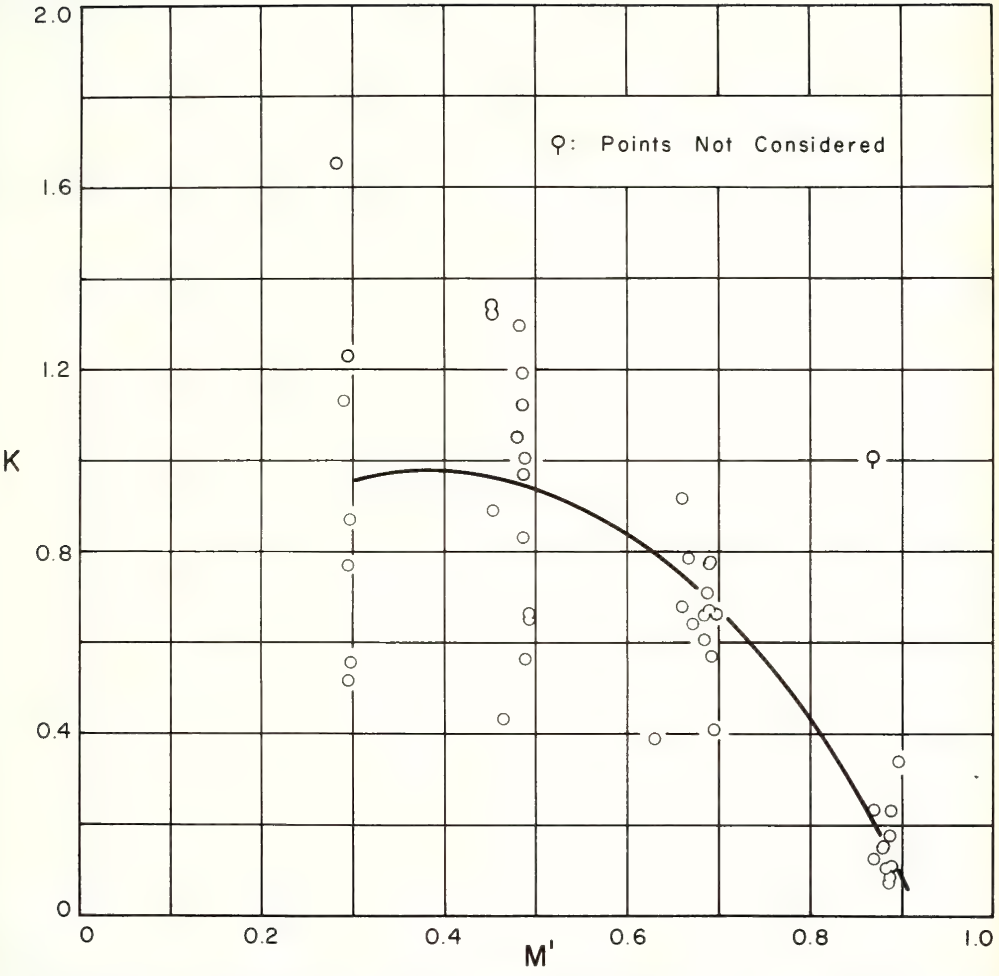


FIGURE 7-2-15 HEAD LOSS COEFFICIENT, GEOMETRY I_a
ROUGH BOUNDARY, $\frac{L}{B}$ = 0.00

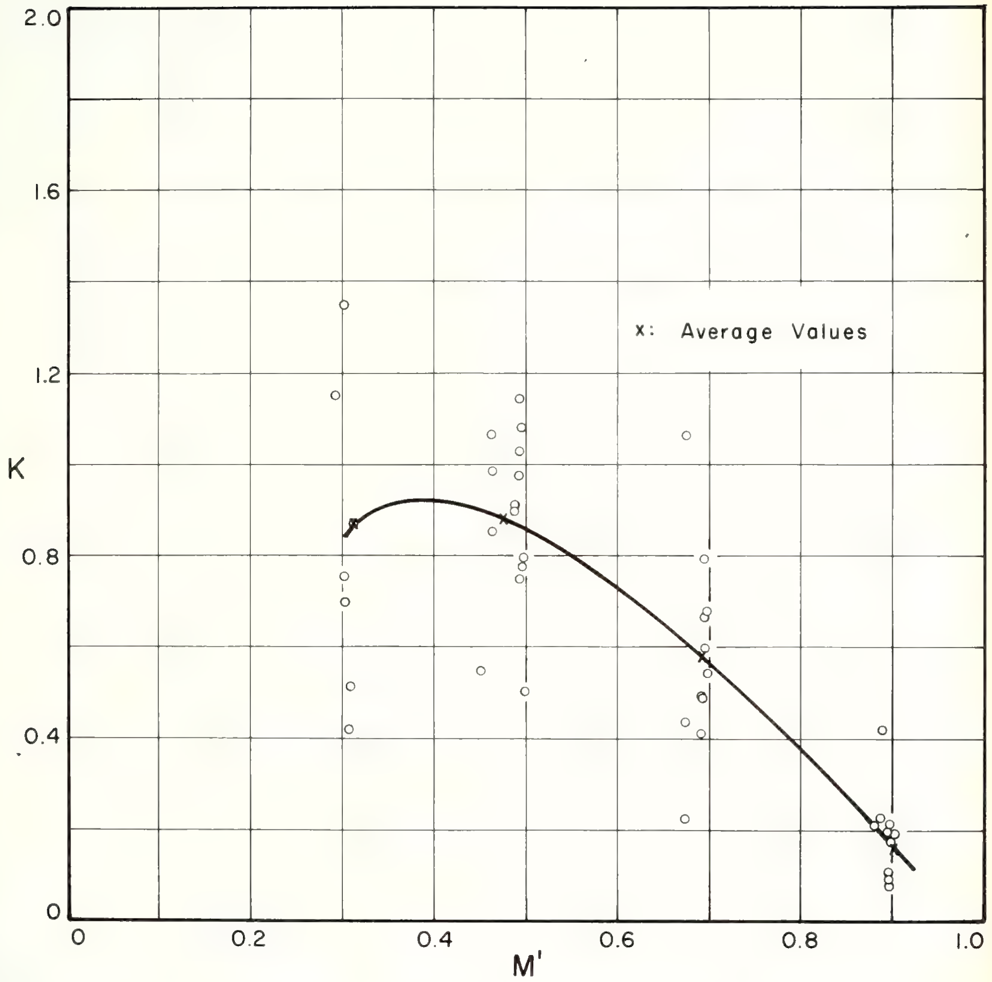


FIGURE 7-2-16 HEAD LOSS COEFFICIENT, GEOMETRY I_b
ROUGH BOUNDARY $\frac{L}{b} = 0.5$

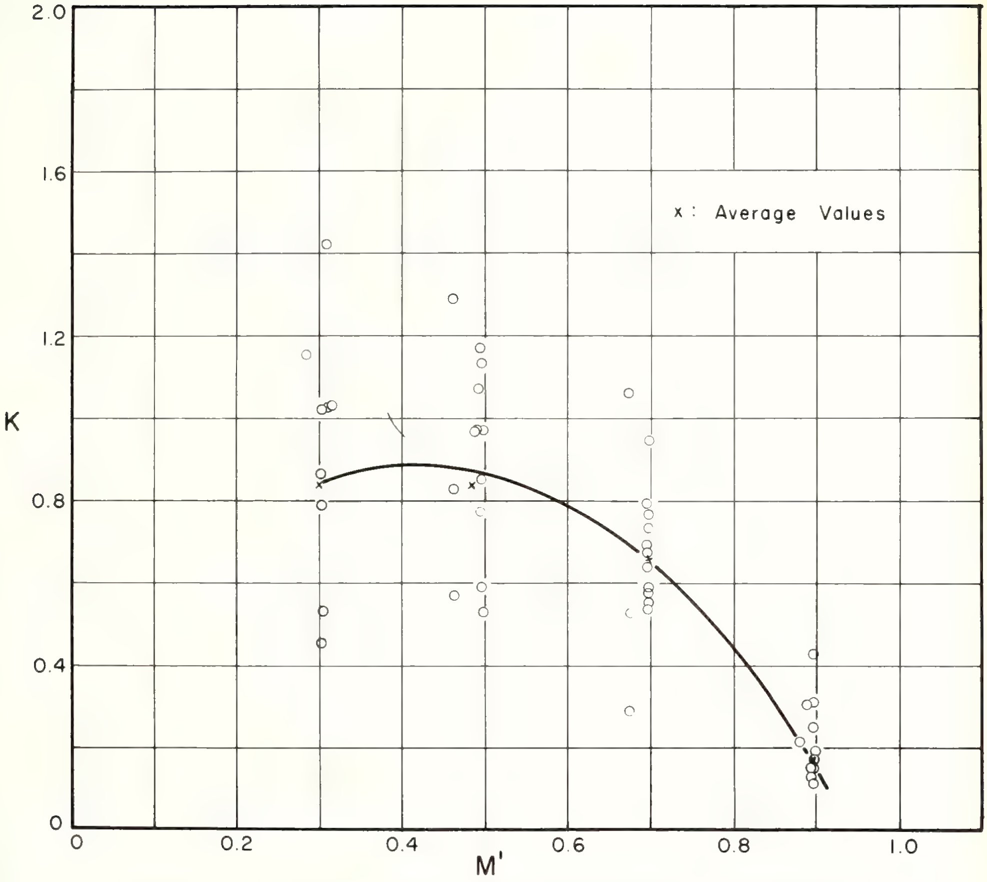


FIGURE 7-2-17 HEAD LOSS COEFFICIENT, GEOMETRY I_b

ROUGH BOUNDARY $\frac{L}{b} = 1.0$

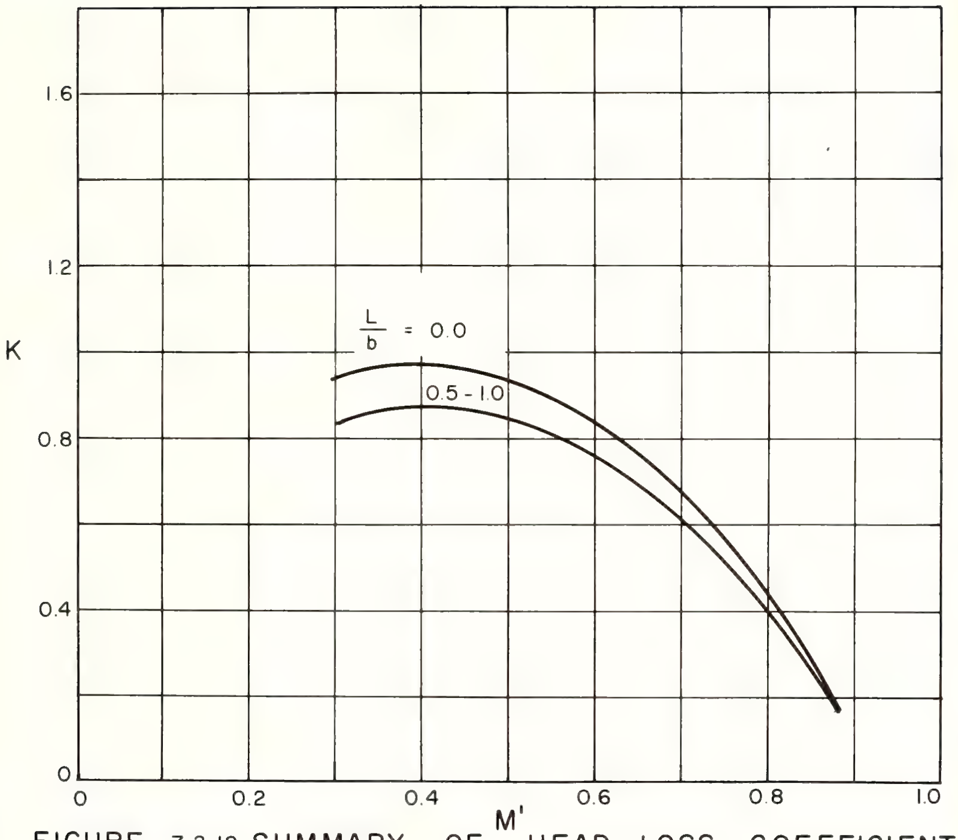


FIGURE 7-2-18 SUMMARY OF HEAD LOSS COEFFICIENTS GEOMETRY Ia & Ib, ROUGH BOUNDARY

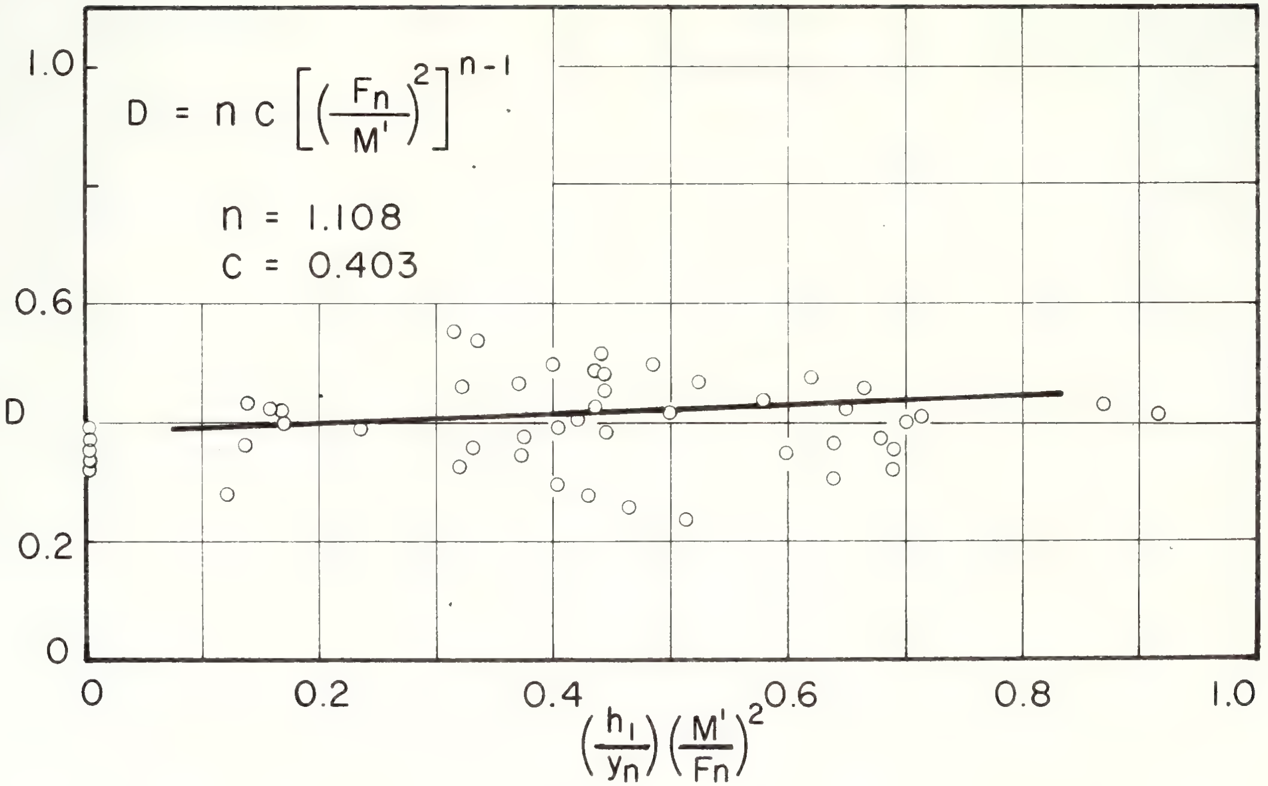


FIGURE 7-2-19 BACKWATER RATIO COEFFICIENT, GEOMETRY Ia

ROUGH BOUNDARY $\frac{L}{b} = 0.00$

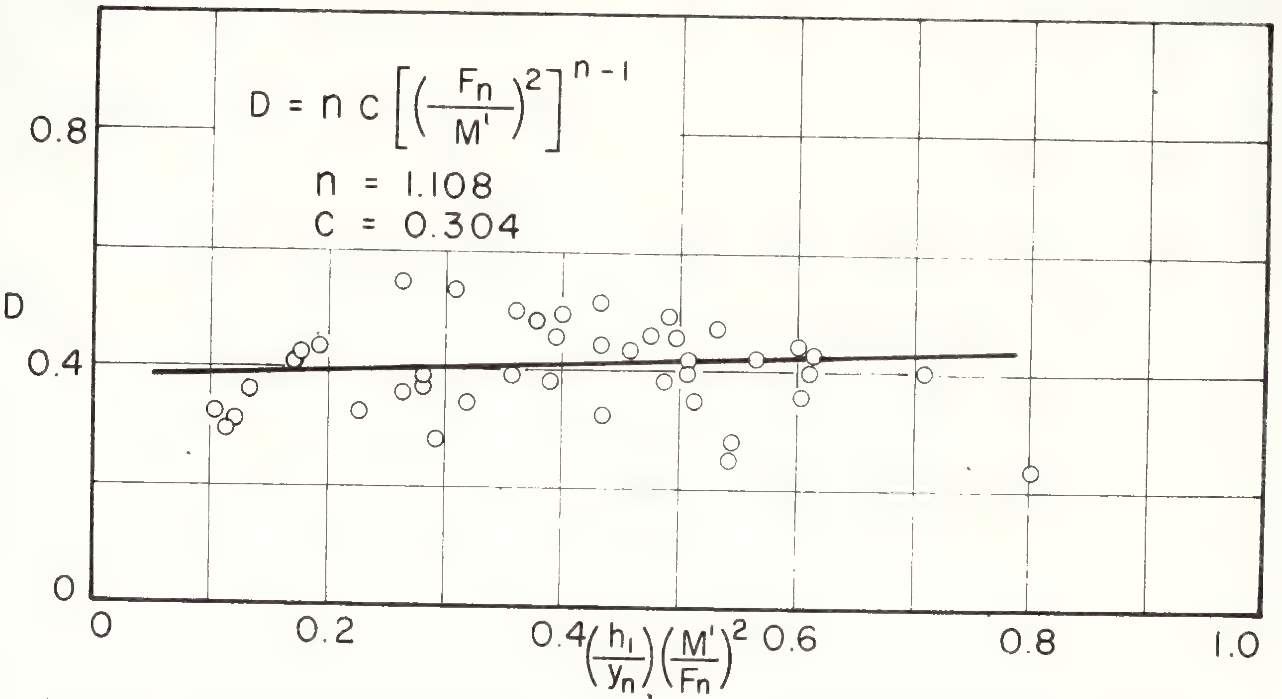


FIGURE 7-2-20 BACKWATER RATIO COEFFICIENT, GEOMETRY I_b, ROUGH BOUNDARY $\frac{L}{b} = 0.5$

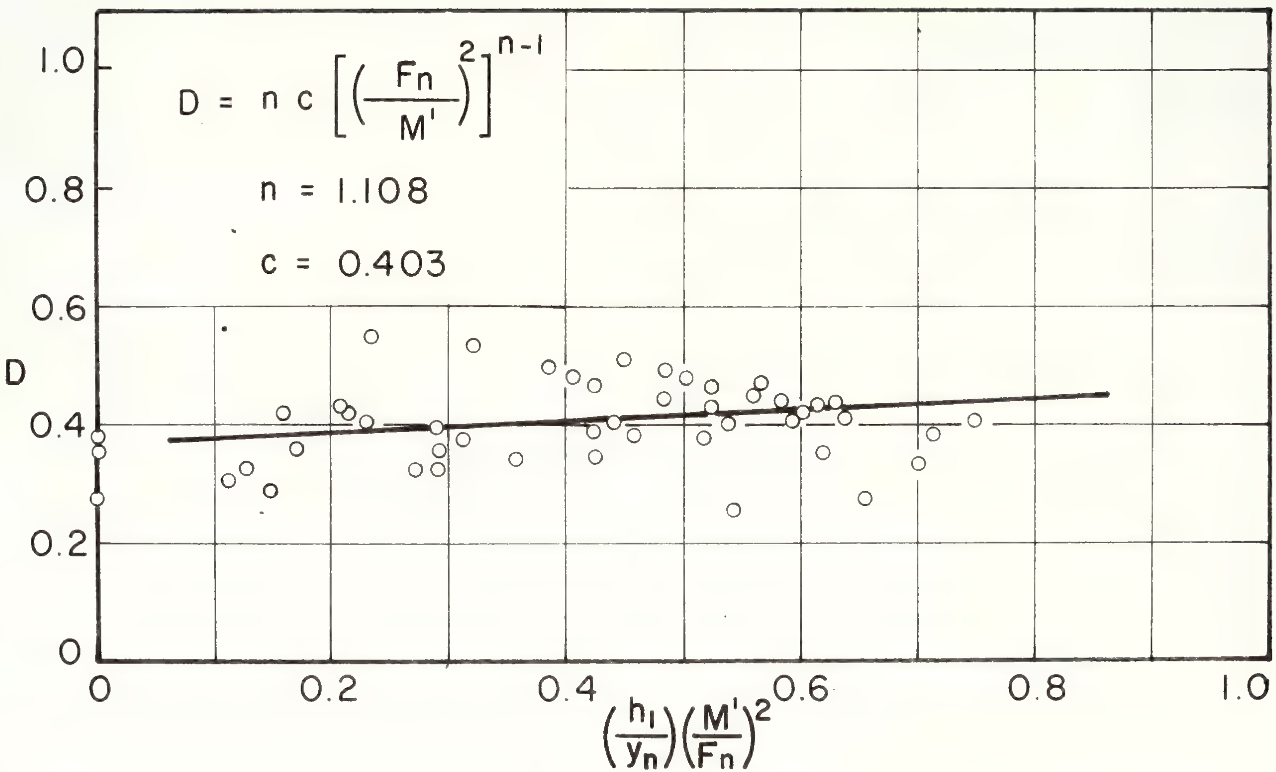
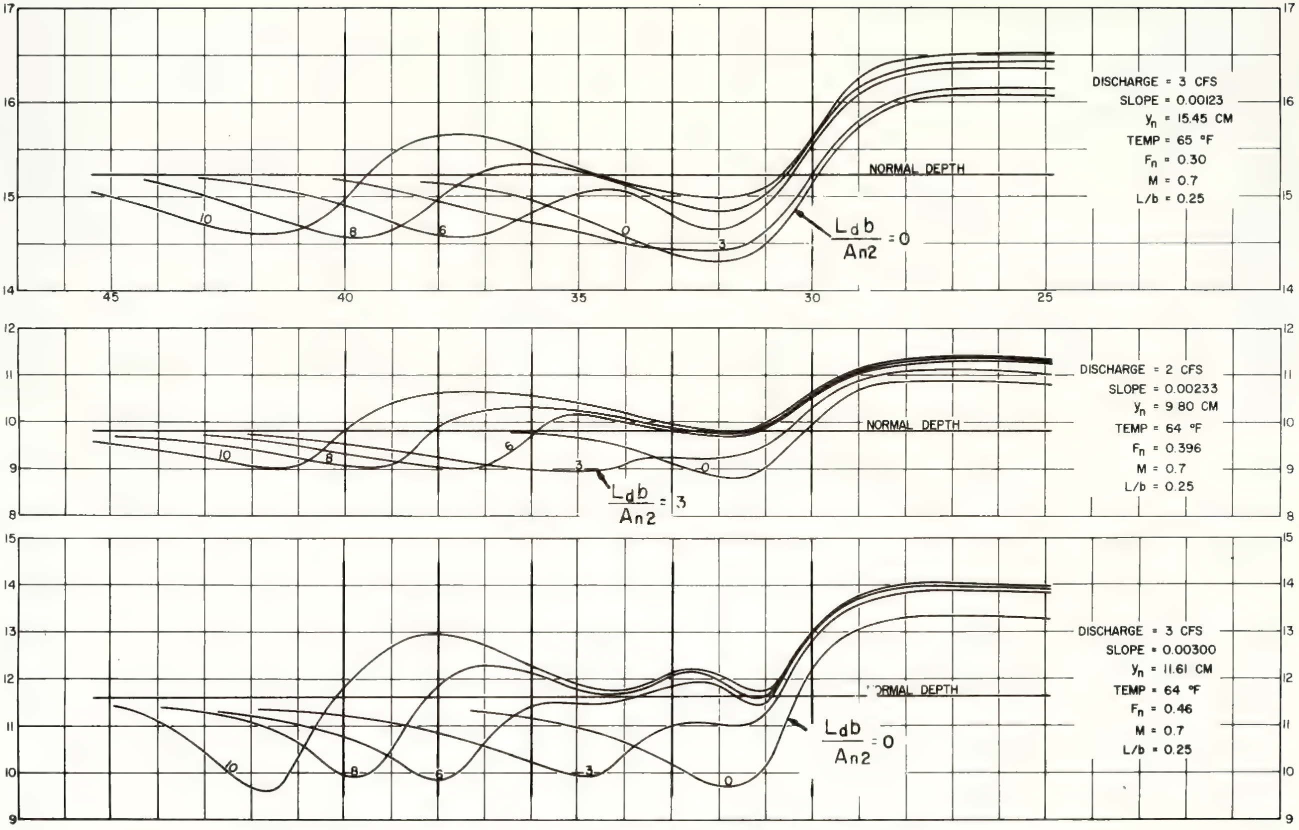


FIGURE 7-2-21 BACKWATER RATIO COEFFICIENT, GEOMETRY I_b

ROUGH BOUNDARY $\frac{L}{b} = 1.0$



MEASURED WATER SURFACE PROFILES ALONG THE CENTERLINE FOR THREE DIMENSIONAL DUAL PARALLEL ARCH BRIDGE MODELS

FIG. 7-3-0

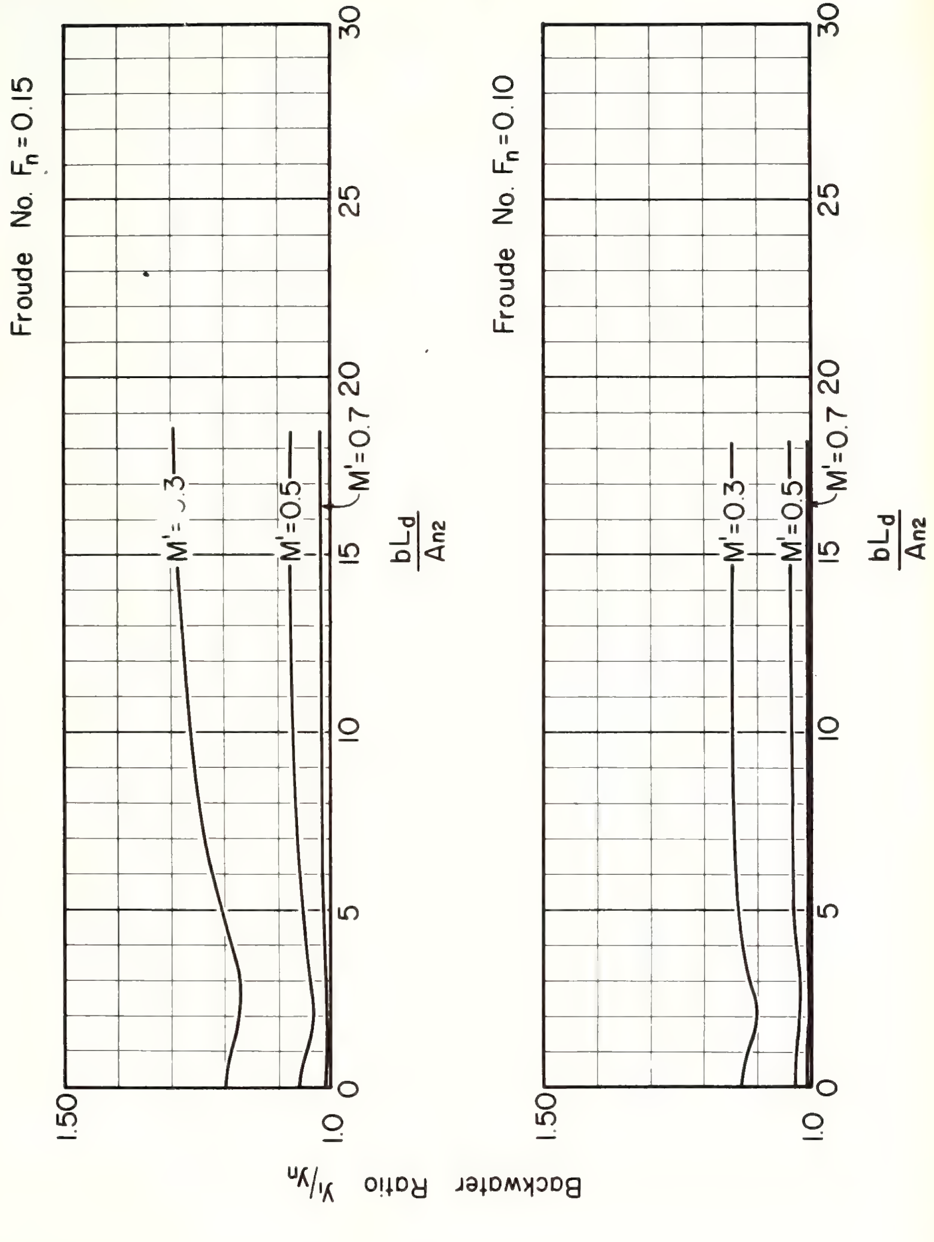


FIG. 7-3-1 BACKWATER RATIO FOR DUAL PARALLEL BRIDGES

F_n=0.10, AND 0.15

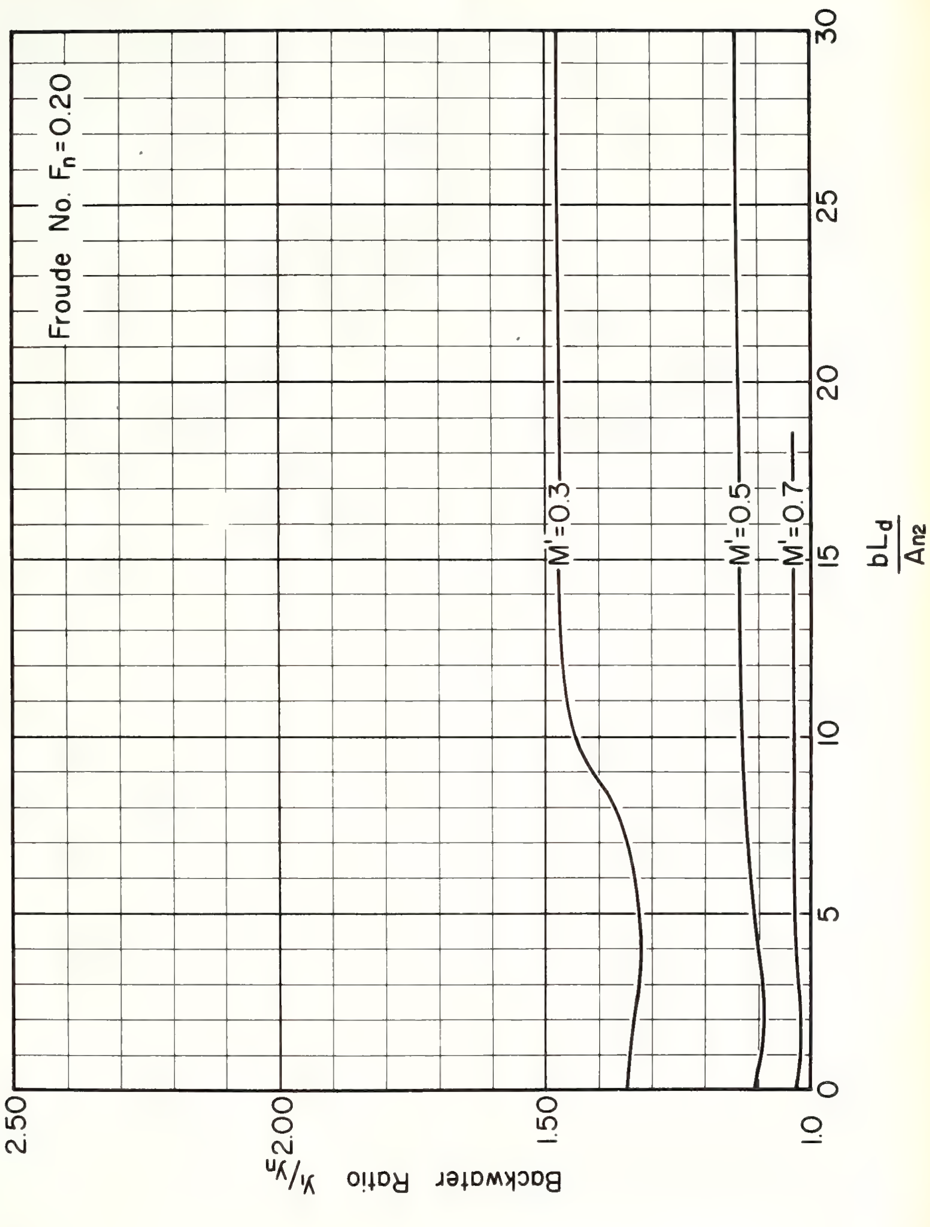


FIG. 7-3-2 BACKWATER RATIO FOR DUAL PARALLEL BRIDGES

$F_n = 0.20$

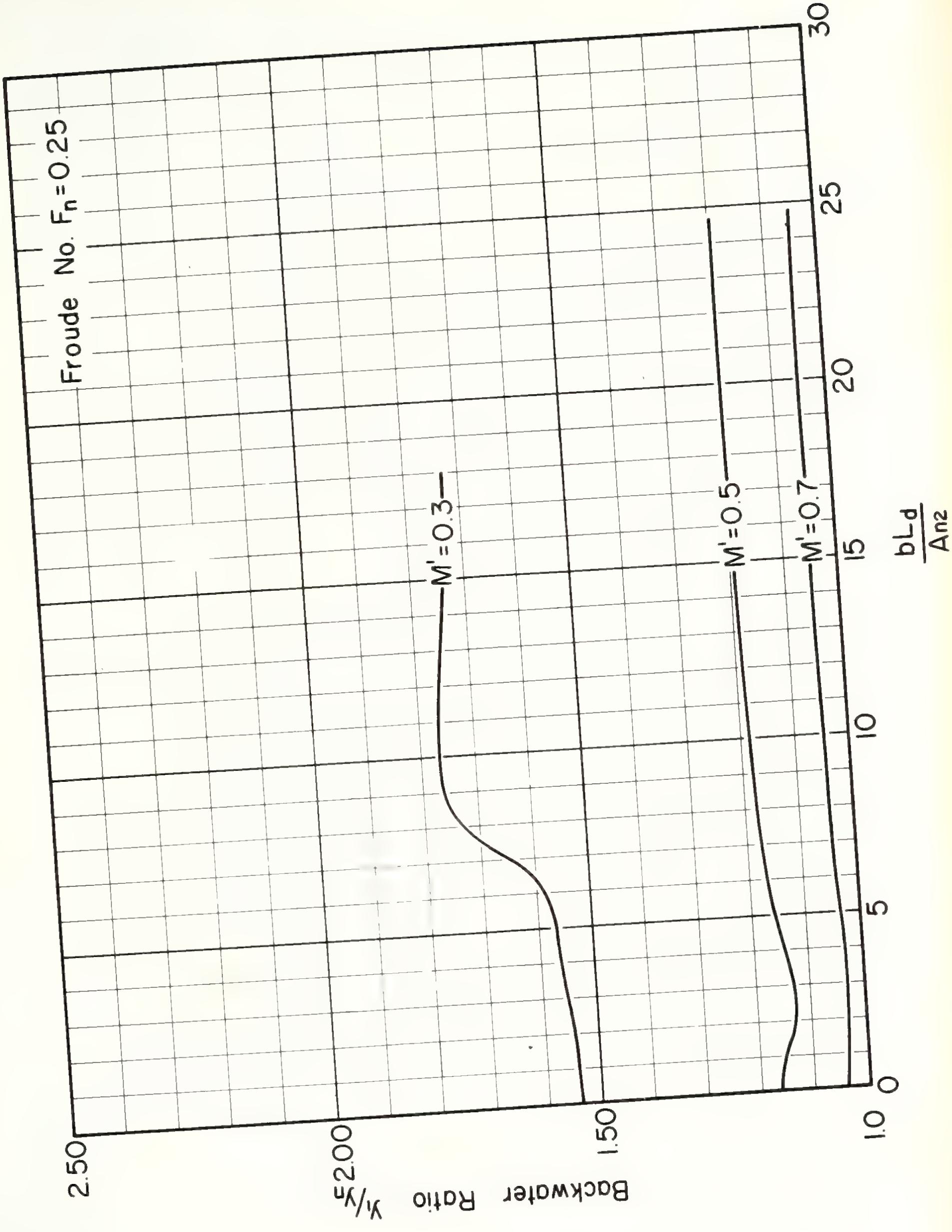


FIG. 7-3-3 BACKWATER RATIO FOR DUAL PARALLEL BRIDGES

$F_n = 0.25$

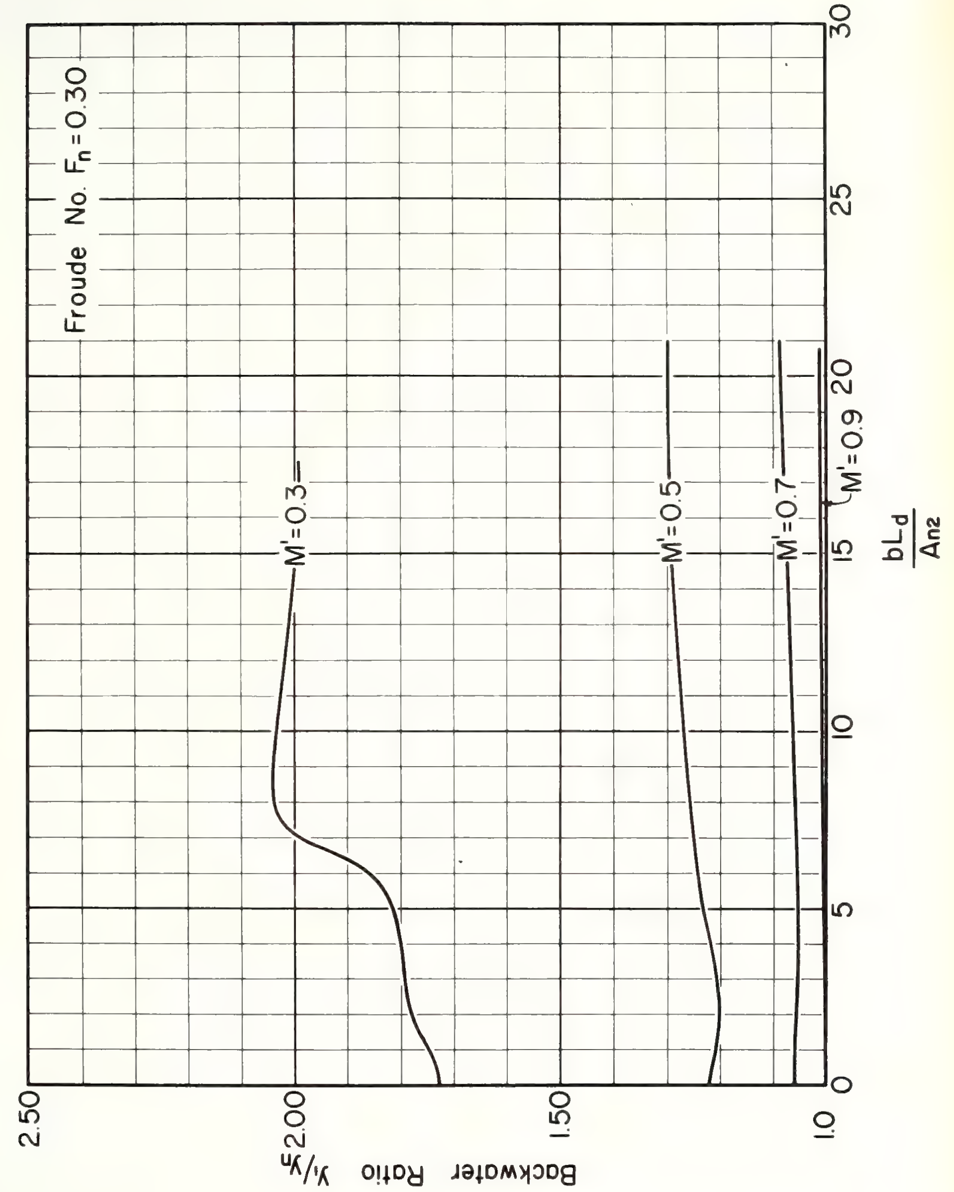


FIG. 7-3-4 BACKWATER RATIO FOR DUAL PARALLEL BRIDGES

$F_n = 0.30$

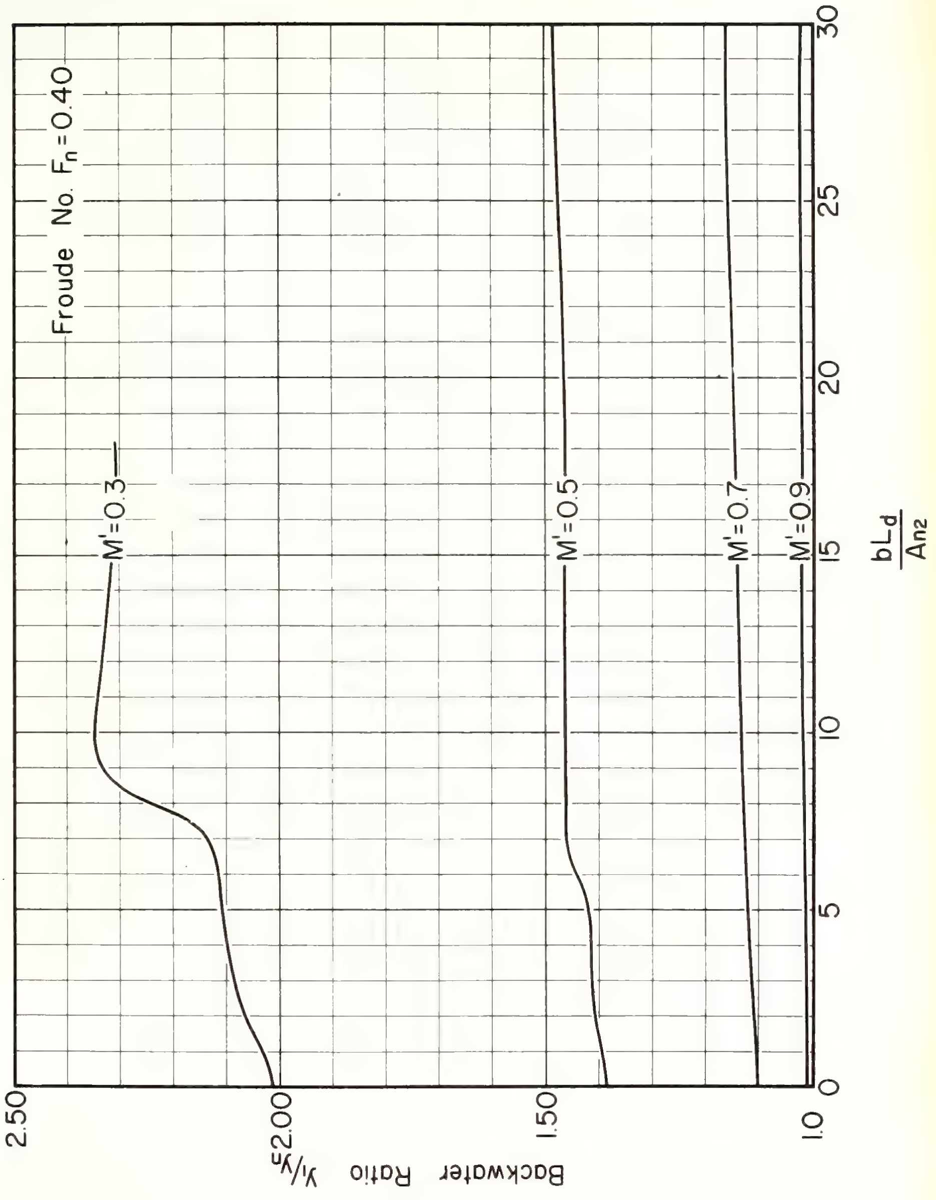


FIG. 7-3-5 BACKWATER RATIO FOR DUAL PARALLEL BRIDGES

$F_n = 0.40$

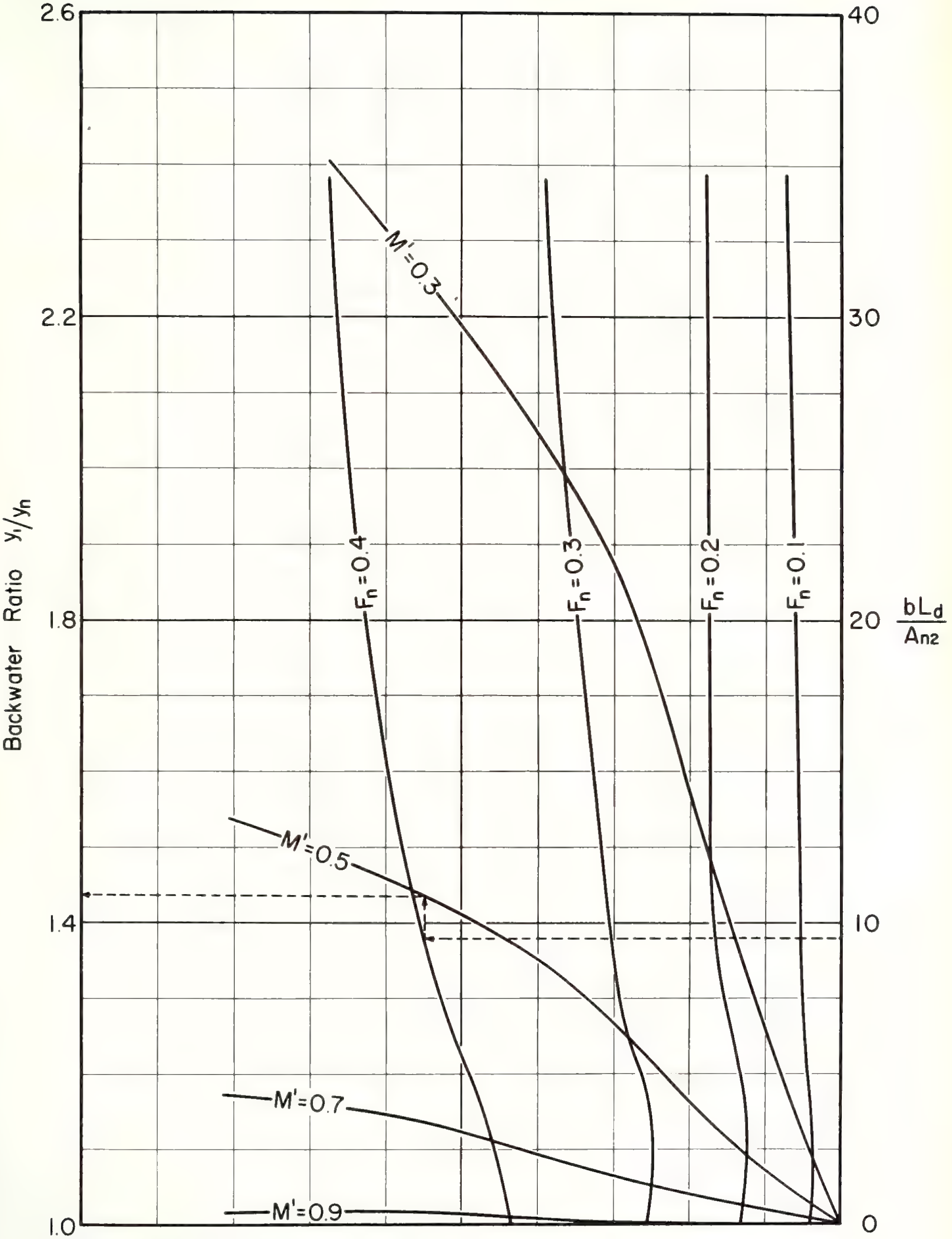
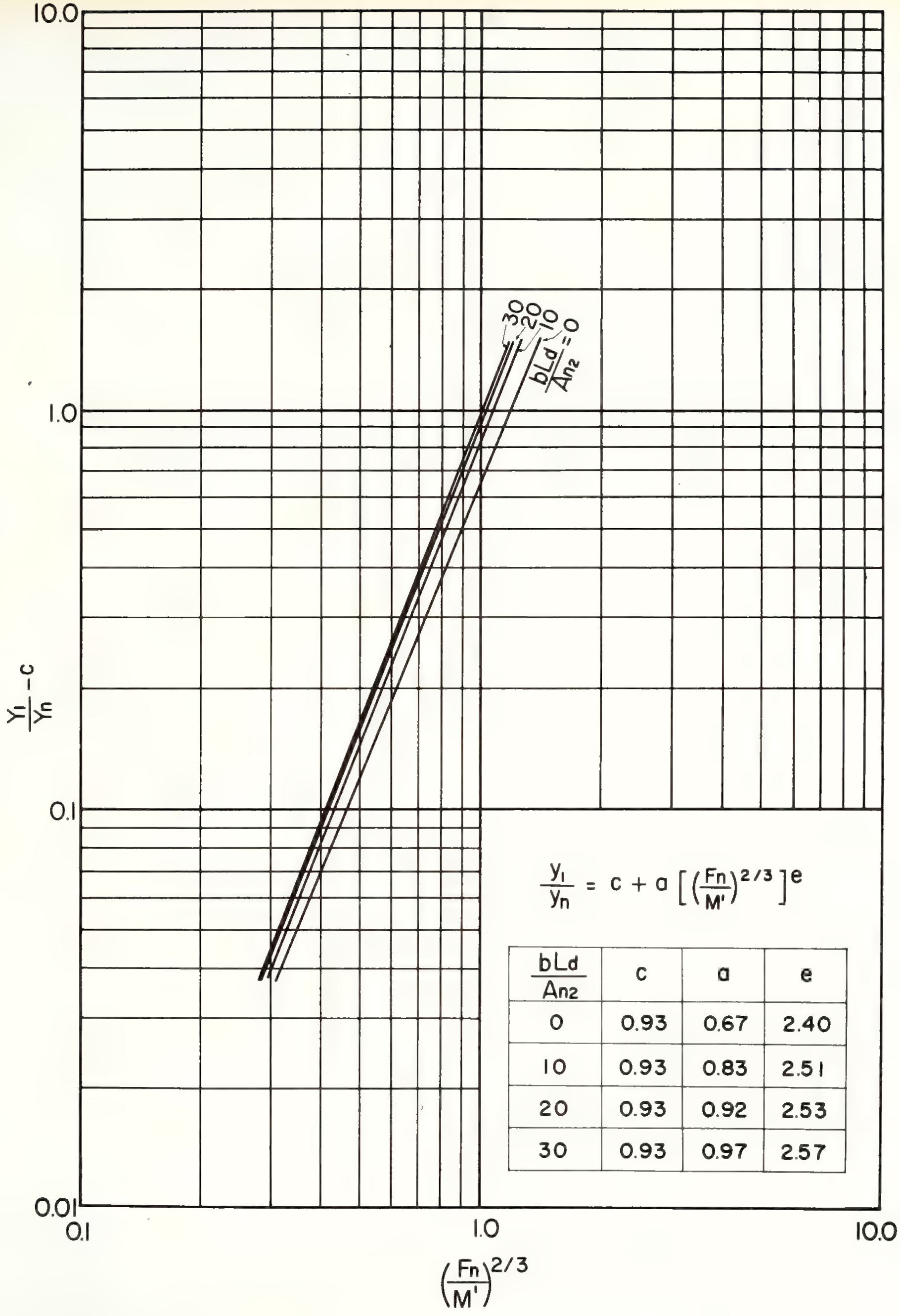


FIG. 7-3-6 BACKWATER RATIO FOR DUAL PARALLEL BRIDGES



$$\frac{y_1}{y_n} = c + a\left[\left(\frac{Fn}{M'}\right)^{2/3}\right]^e$$

$\frac{bLd}{An_2}$	c	a	e
0	0.93	0.67	2.40
10	0.93	0.83	2.51
20	0.93	0.92	2.53
30	0.93	0.97	2.57

FIG. 7-3-7 - GENERALIZED BACKWATER RATIO FOR DUAL PARALLEL BRIDGES

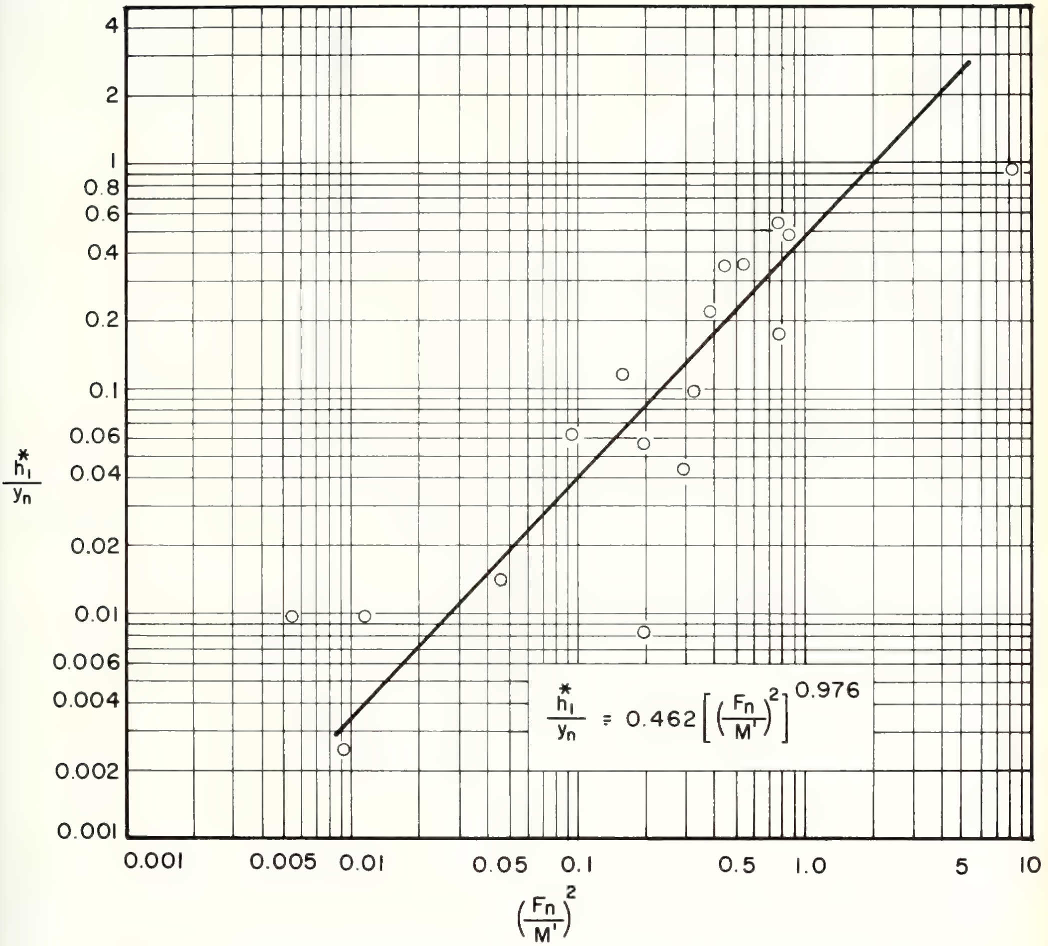


FIGURE 7-3-8 BACKWATER RATIO, GEOMETRY II

ROUGH BOUNDARY $\frac{L_d b}{A_{n2}} = 0.00$

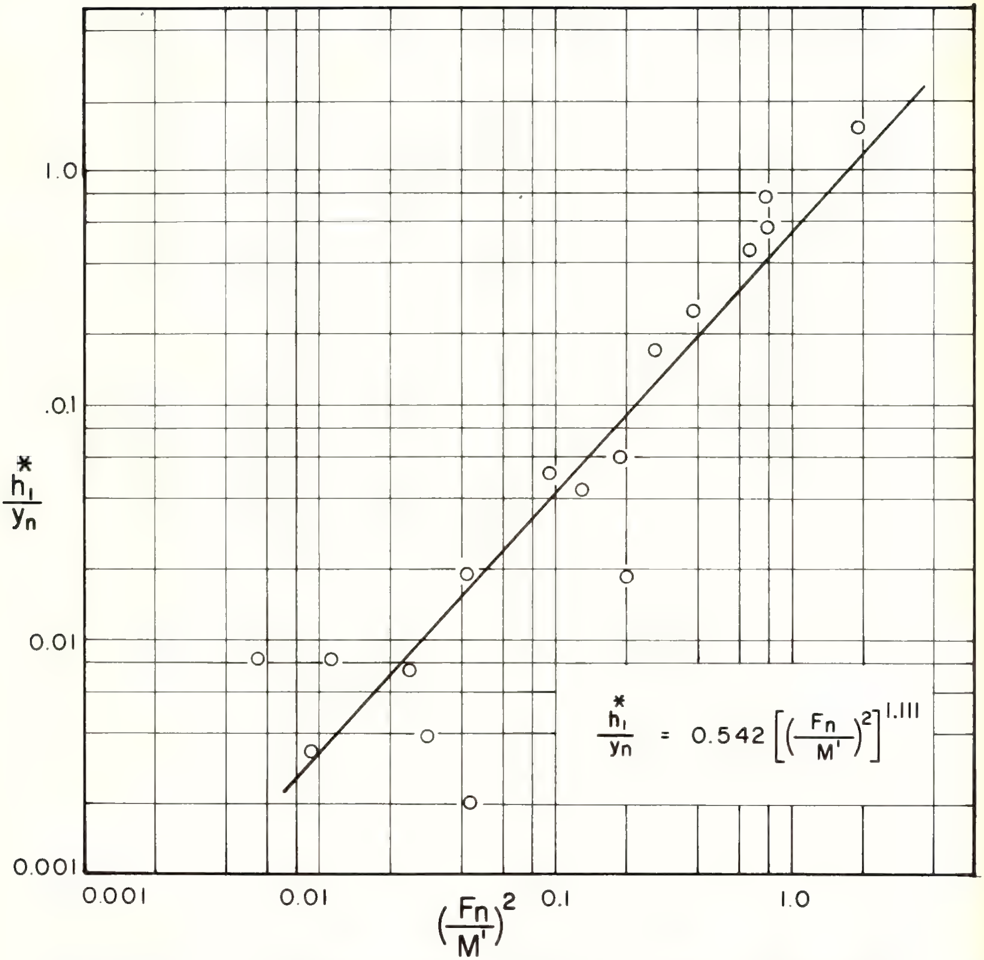


FIGURE 7-3-9 BACKWATER RATIO FOR GEOMETRY II ROUGH BOUNDARY $0 < \frac{L_d b}{A_{n2}} \leq 7.5$

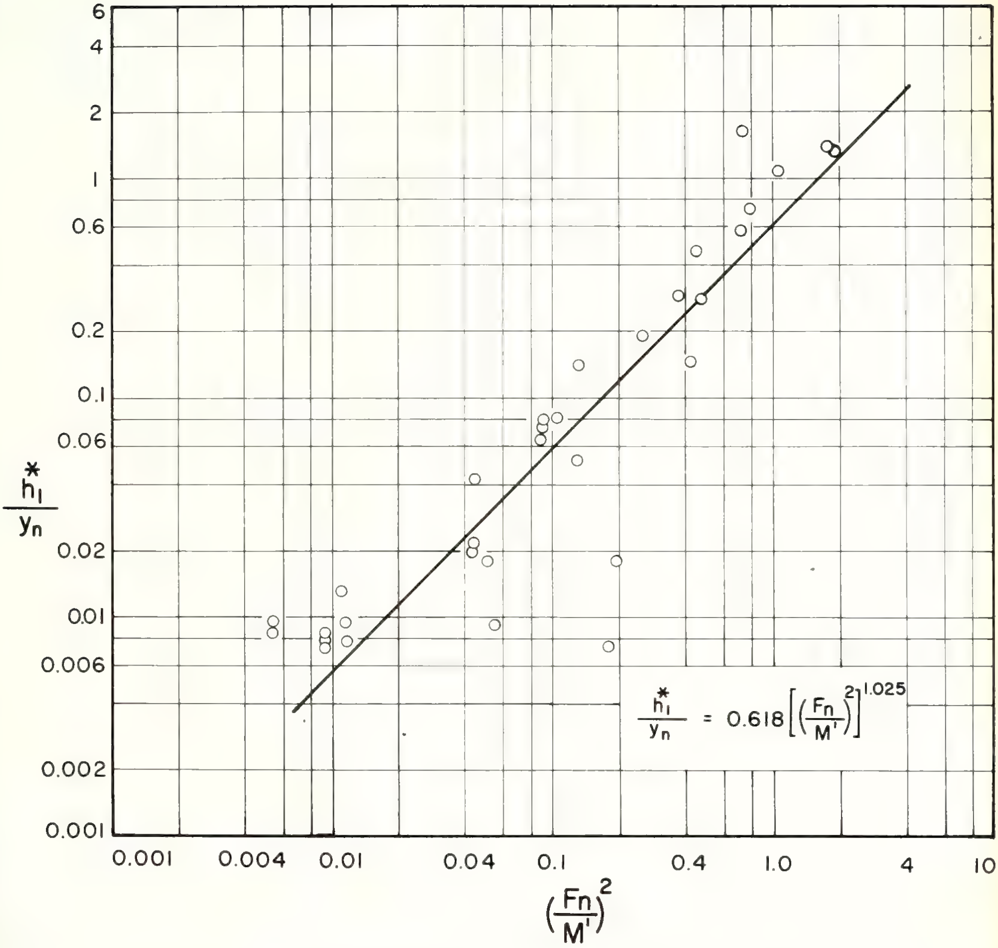


FIGURE 7-3-10 BACKWATER RATIO, GEOMETRY II
ROUGH BOUNDARY $\frac{L_{db}}{A_{n2}} = 7.5 - 15$

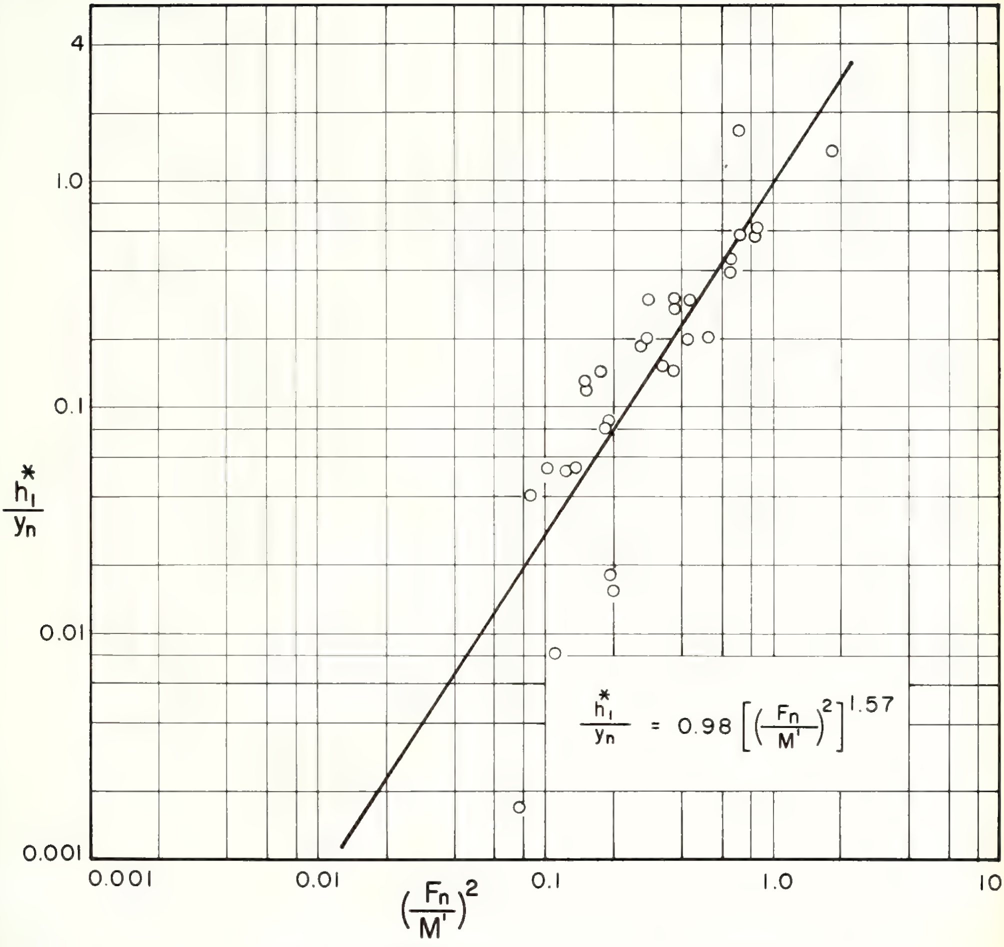


FIGURE 7-3-11 BACKWATER RATIO, GEOMETRY II

ROUGH BOUNDARY $\frac{L_d b}{A_{n2}}$ = 15 - 25

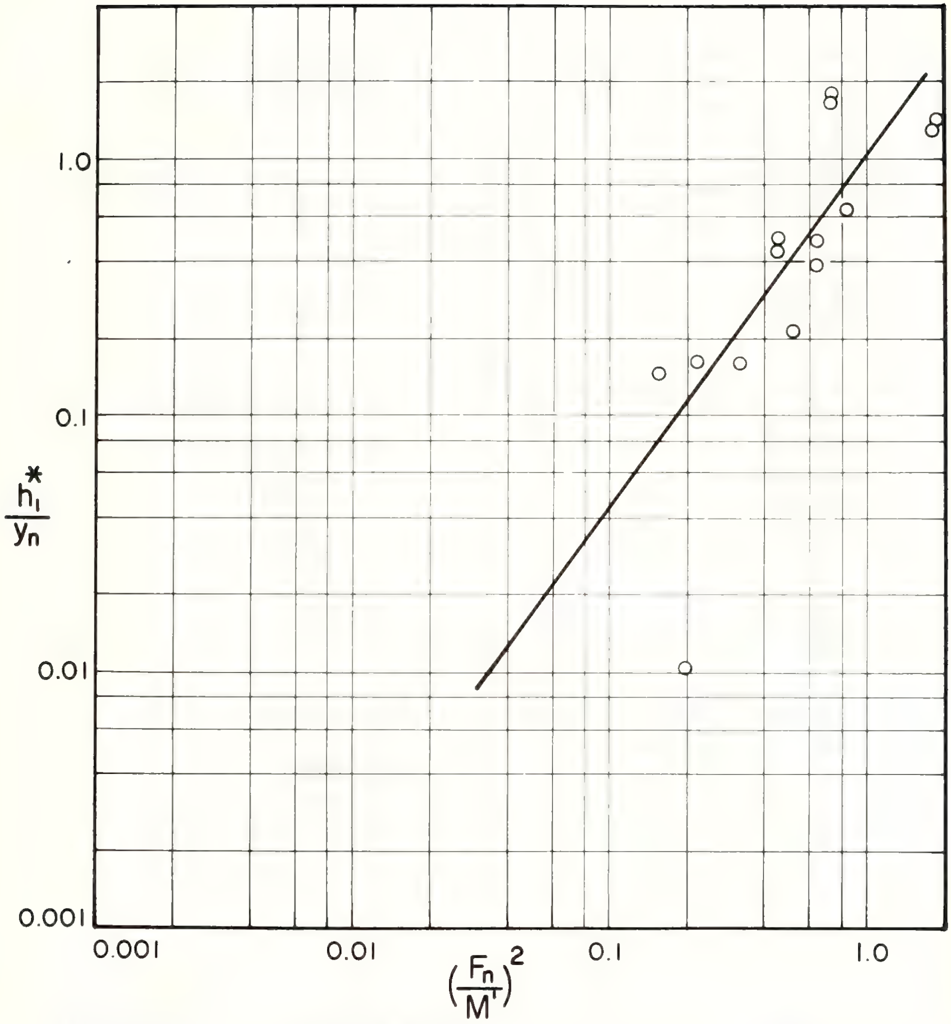


FIGURE 7-3-12 BACKWATER RATIO, GEOMETRY II ROUGH BOUNDARY $\frac{L_{db}}{A_{n2}} = 25-30$

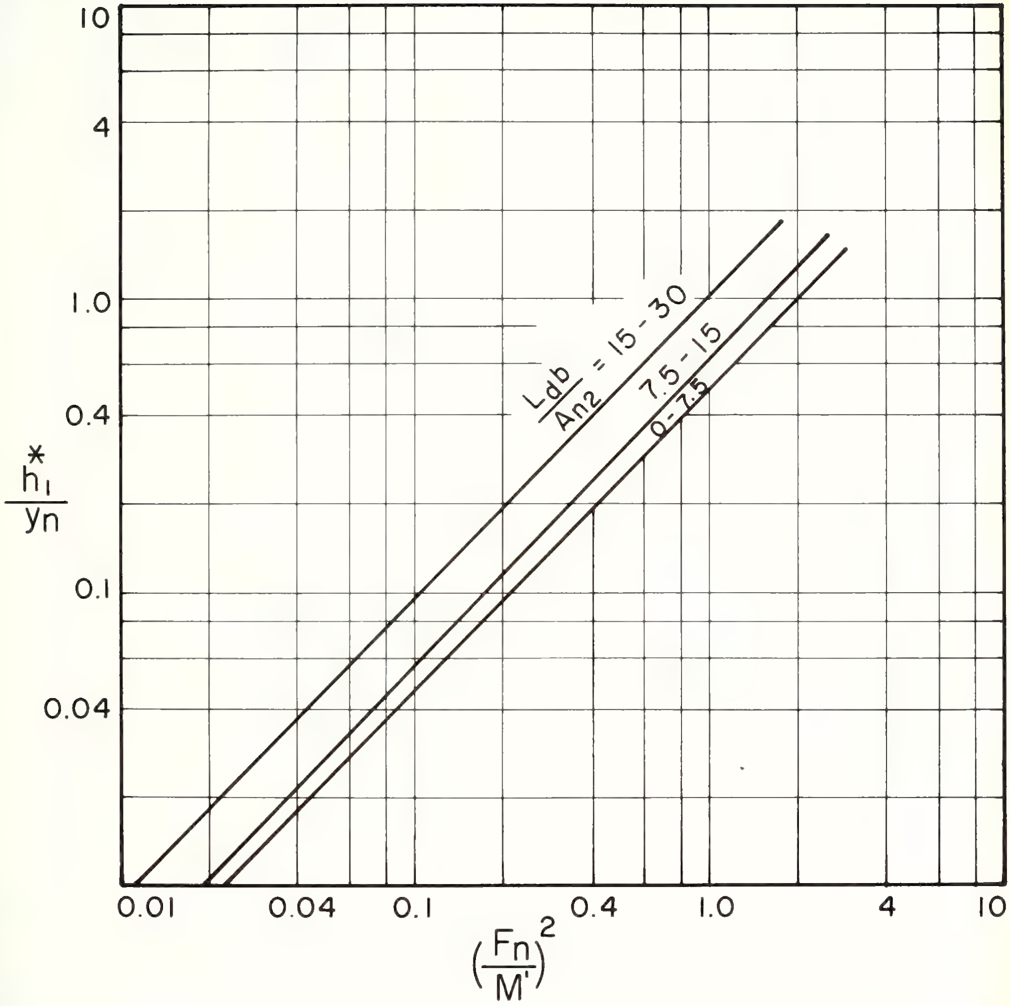


FIGURE 7-3-13 SUMMARY OF BACKWATER RATIO, GEOMETRY II ROUGH BOUNDARY

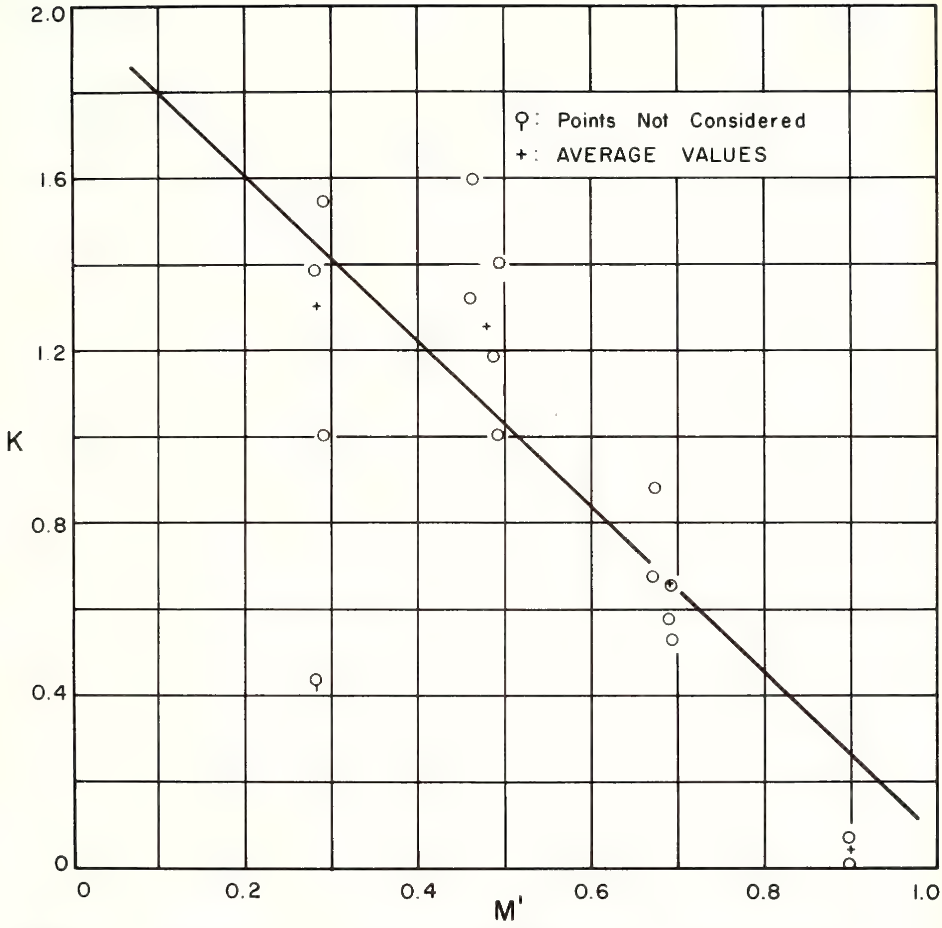


FIGURE 7-3-14 HEAD LOSS COEFFICIENT, GEOMETRY II

ROUGH BOUNDARY $\frac{L_d b}{A_{n2}} = 0.00$

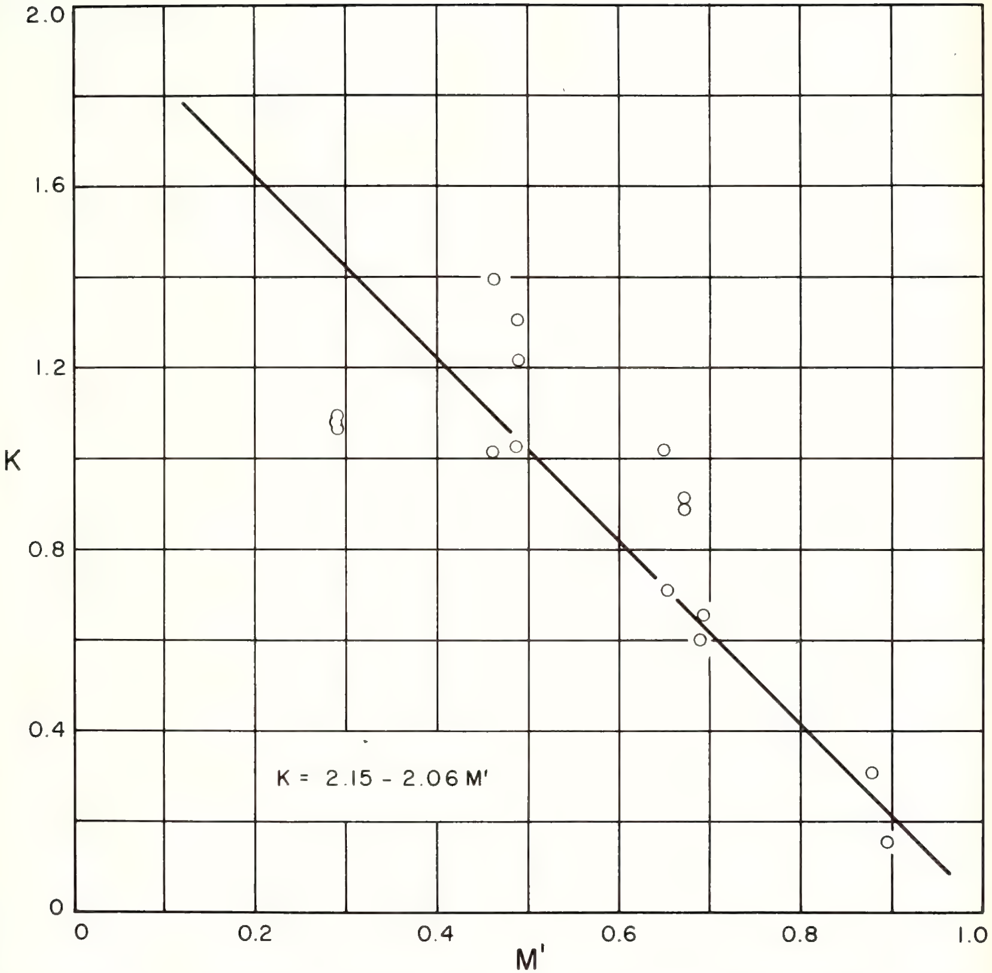


FIGURE 7-3-15 HEAD LOSS COEFFICIENT, GEOMETRY II
ROUGH BOUNDARY $\frac{L_d b}{A_{n2}} > 0 \leq 7.5$

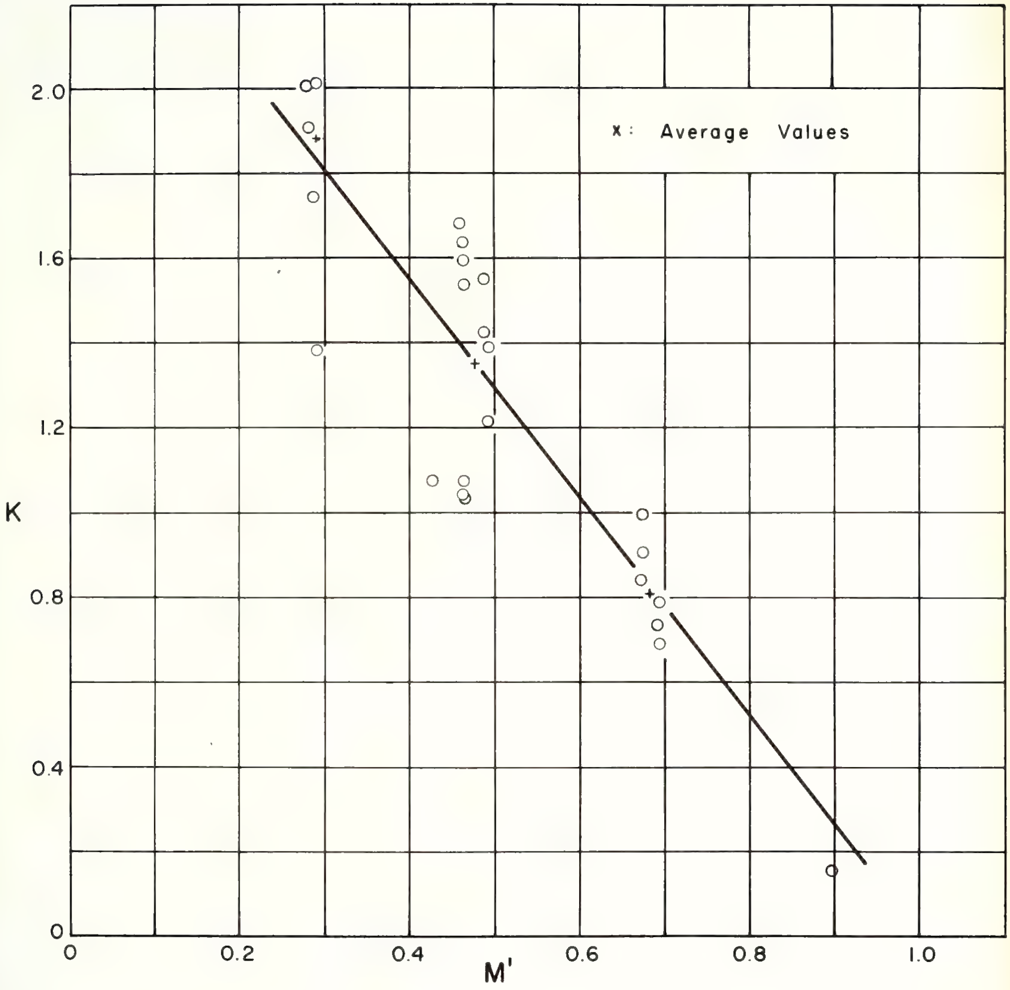


FIGURE 7-3-16 HEAD LOSS COEFFICIENT, GEOMETRY II ROUGH BOUNDARY $\frac{L_d b}{A_{n2}} = 7.5 - 15$

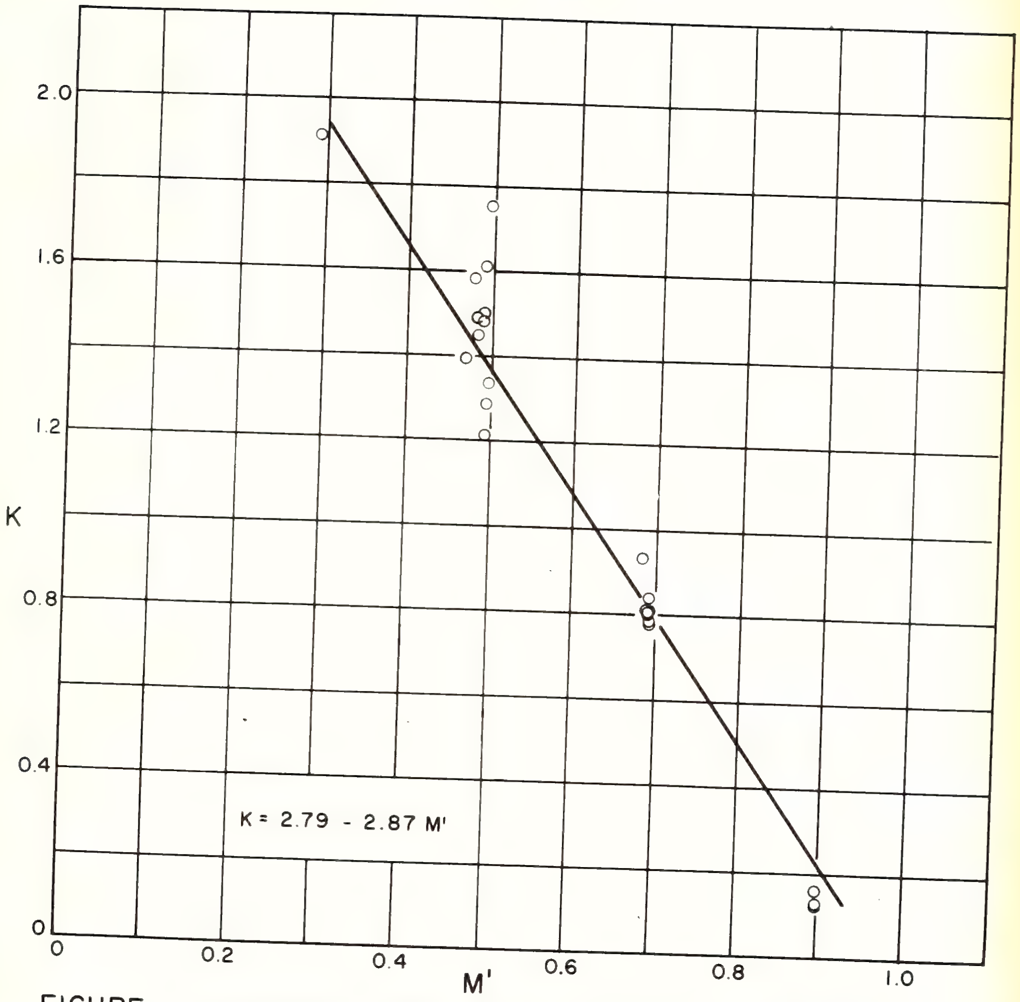


FIGURE 7-3-17 HEAD LOSS COEFFICIENT, GEOMETRY II ROUGH BOUNDARY $\frac{Ldb}{A_{n2}}$ = 15 - 25

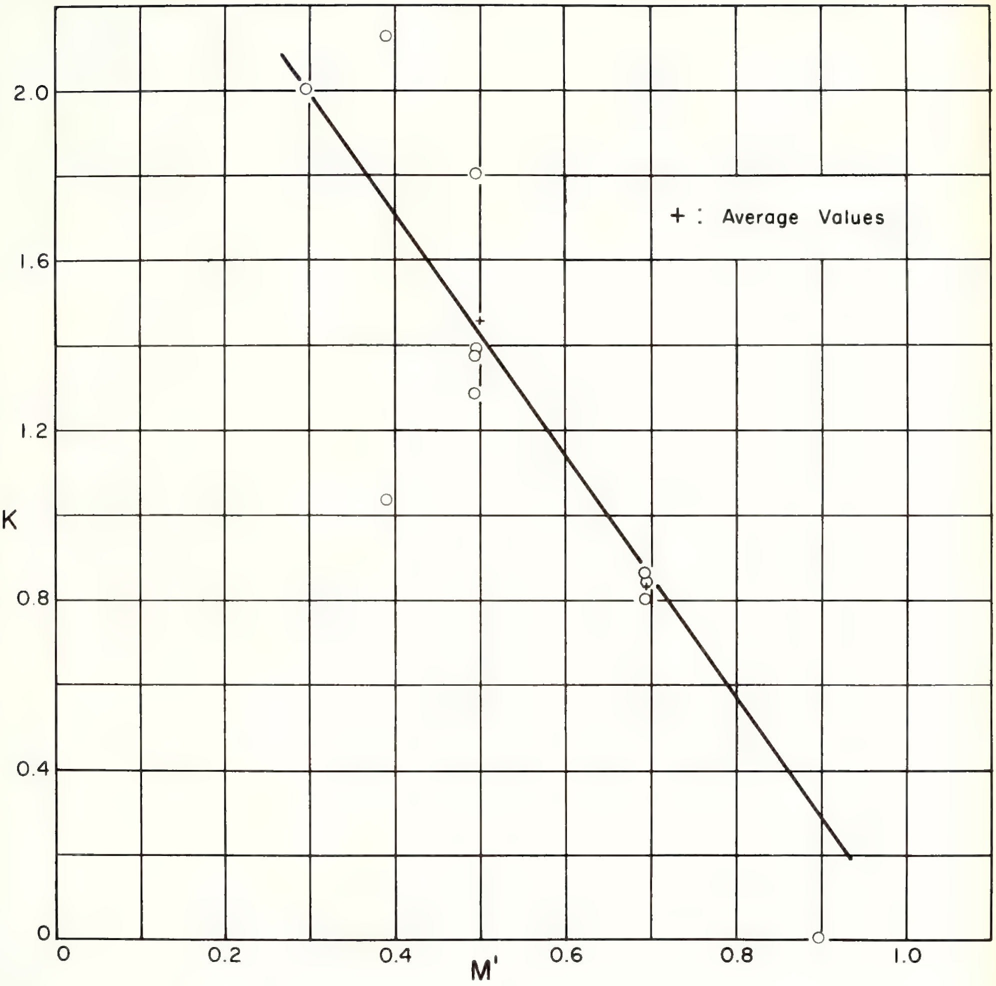


FIGURE 7-3-18. HEAD LOSS COEFFICIENT, GEOMETRY II
ROUGH BOUNDARY $\frac{L_d b}{A_{n2}} = 25 - 30$

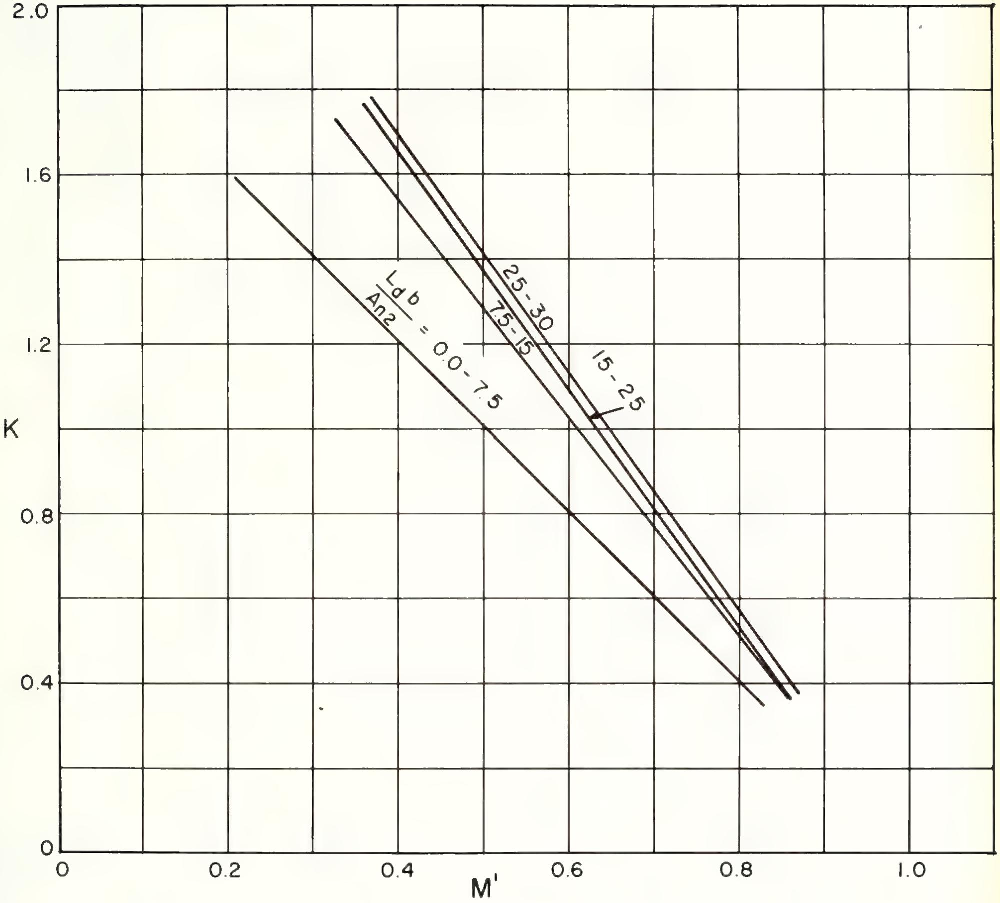


FIGURE 7-3-19 SUMMARY OF HEAD LOSS COEFFICIENTS, GEOMETRY II, ROUGH BOUNDARIES

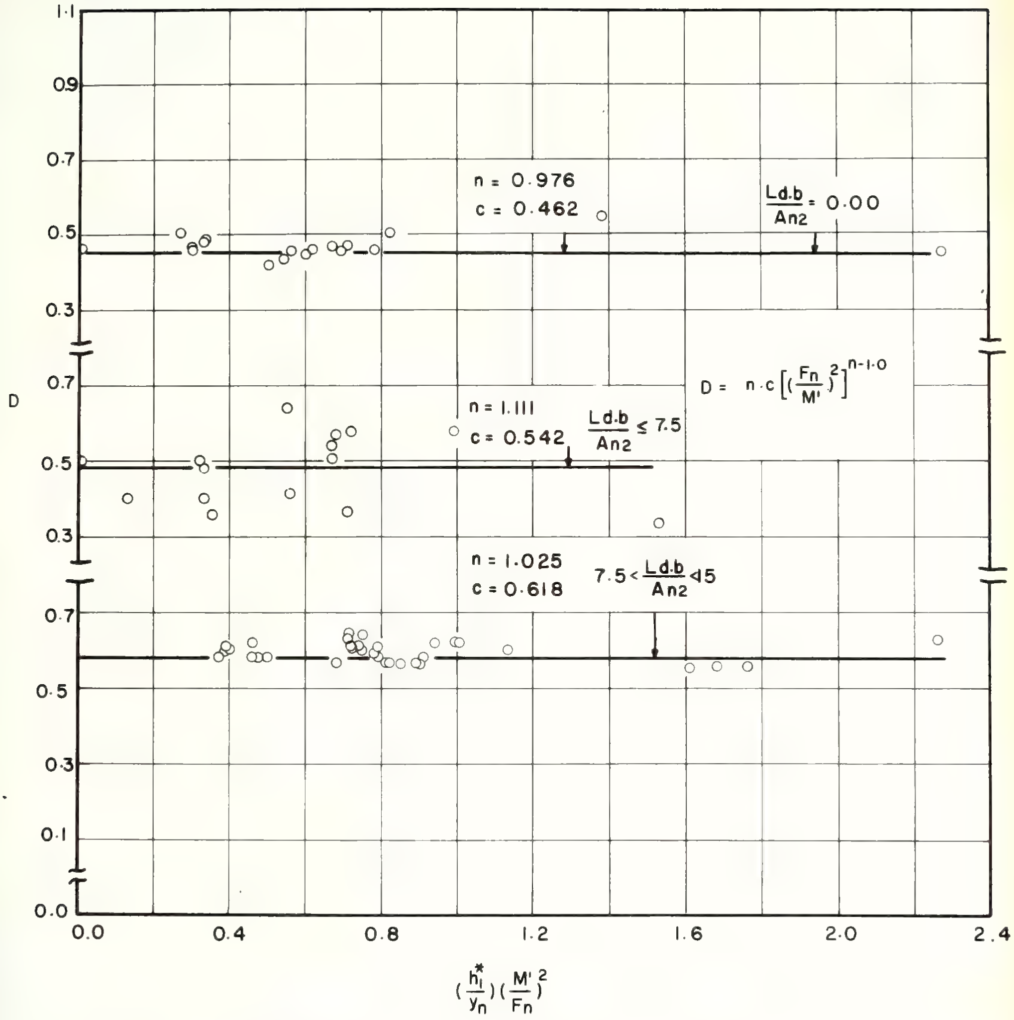


FIGURE 7-3-20 BACKWATER RATIO COEFICIENT GEOMETRY II

ROUGH BOUNDARY

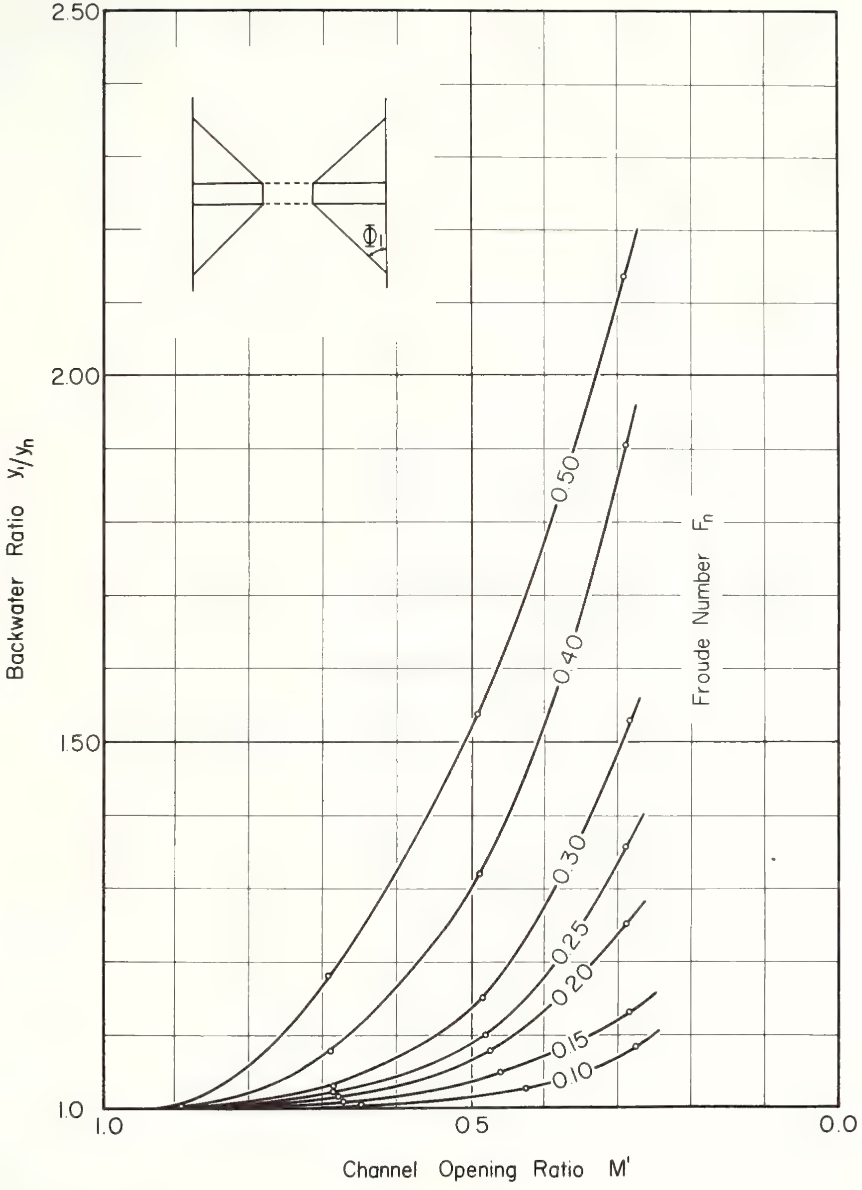


FIG. 7-4-1 BACKWATER RATIO FOR ARCH BRIDGES WITH WINGWALLS $\Phi_1 = 30°$

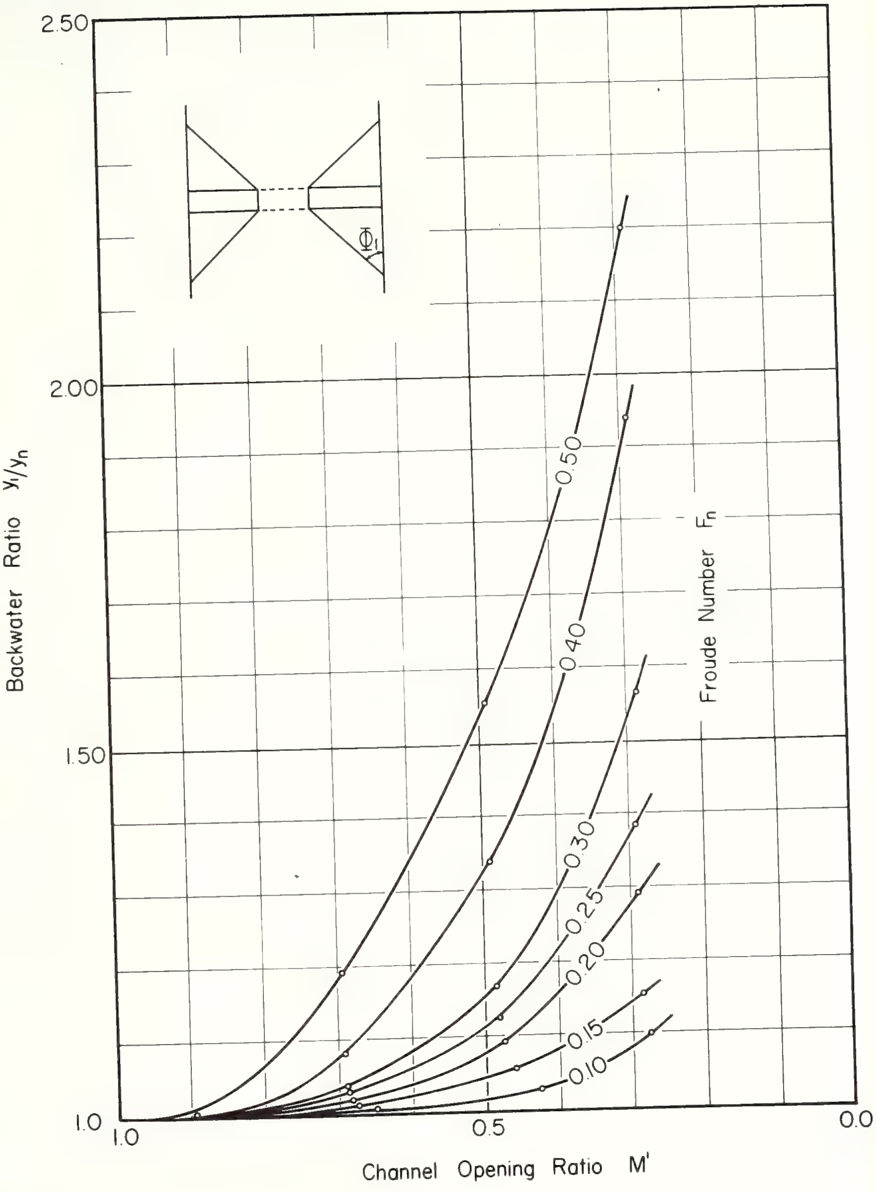


FIG. 7-4-2 BACKWATER RATIO FOR ARCH BRIDGES WITH WINGWALLS $\Phi_1 = 45°$

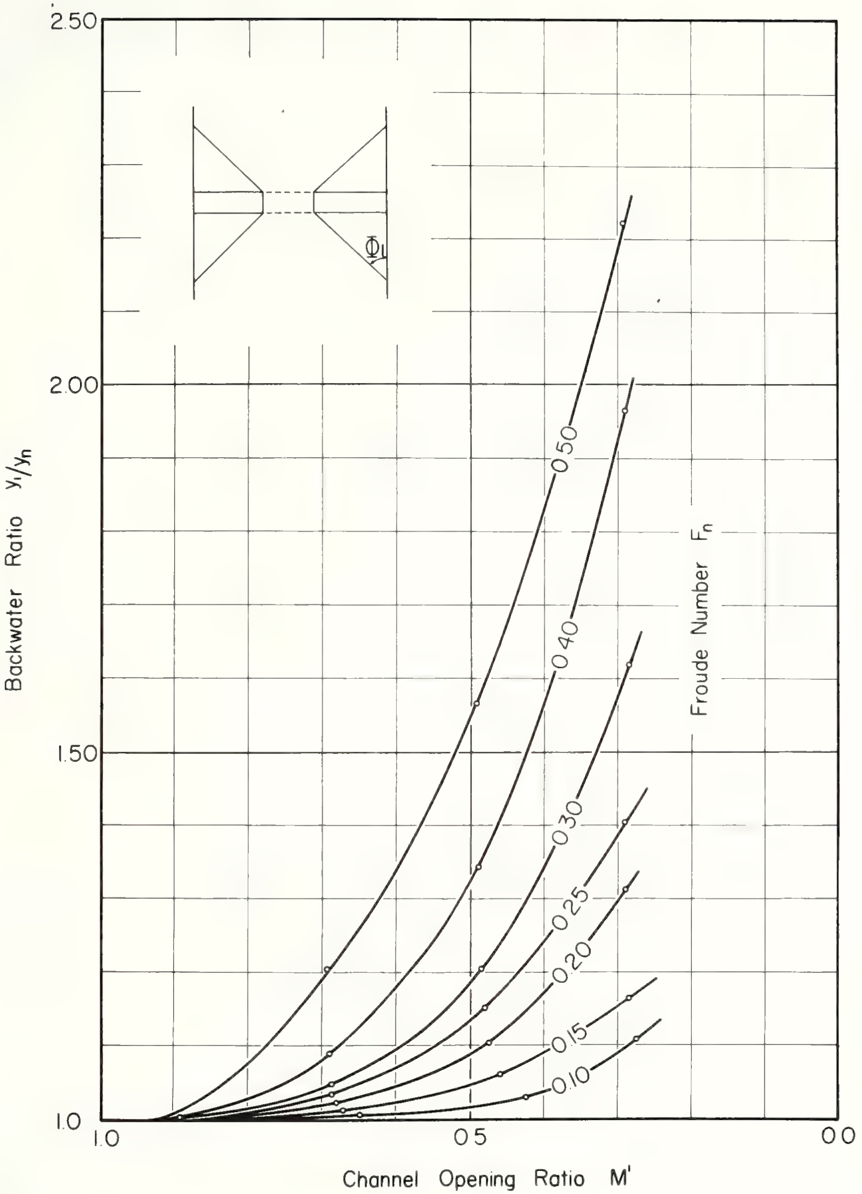


FIG. 7-4-3 BACKWATER RATIO FOR ARCH BRIDGES WITH WINGWALLS $\Phi_1 = 60°$

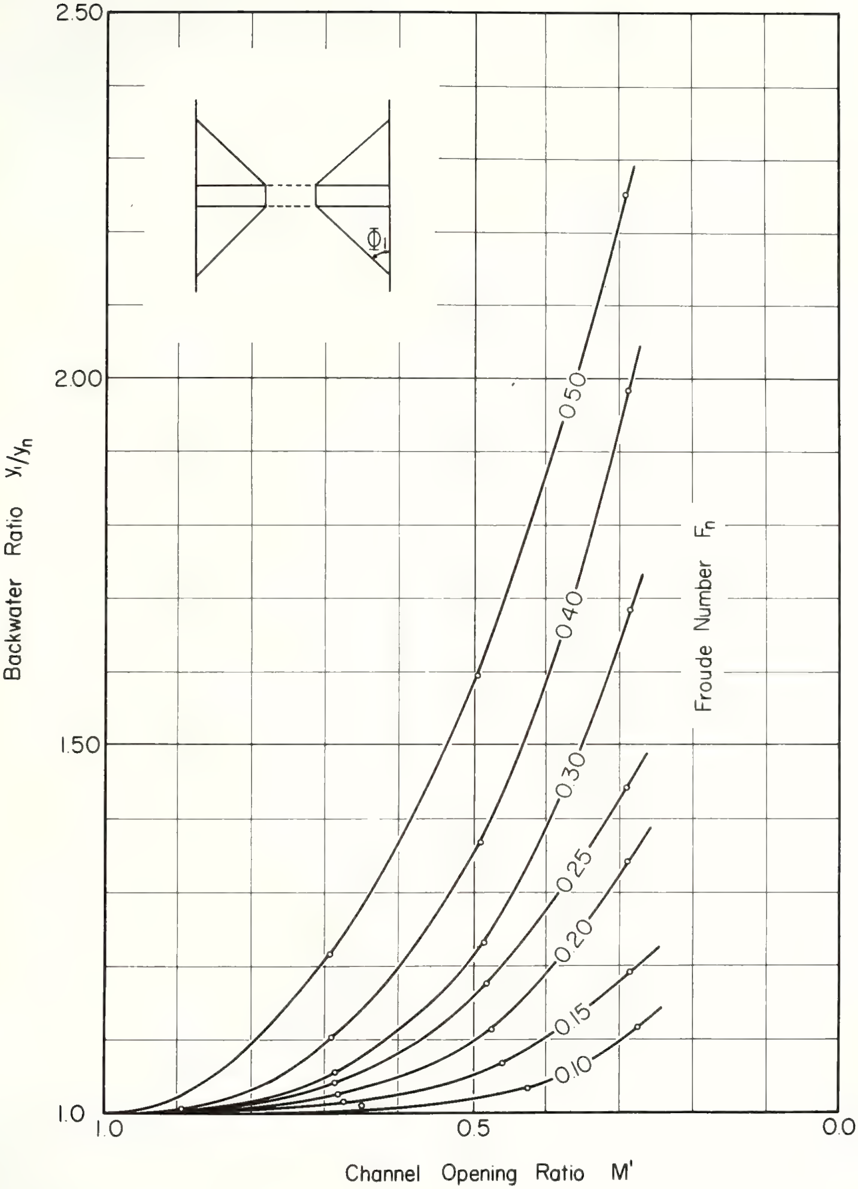


FIG. 7-4-4 BACKWATER RATIO FOR ARCH BRIDGES WITH WINGWALLS $\Phi_1 = 90°$

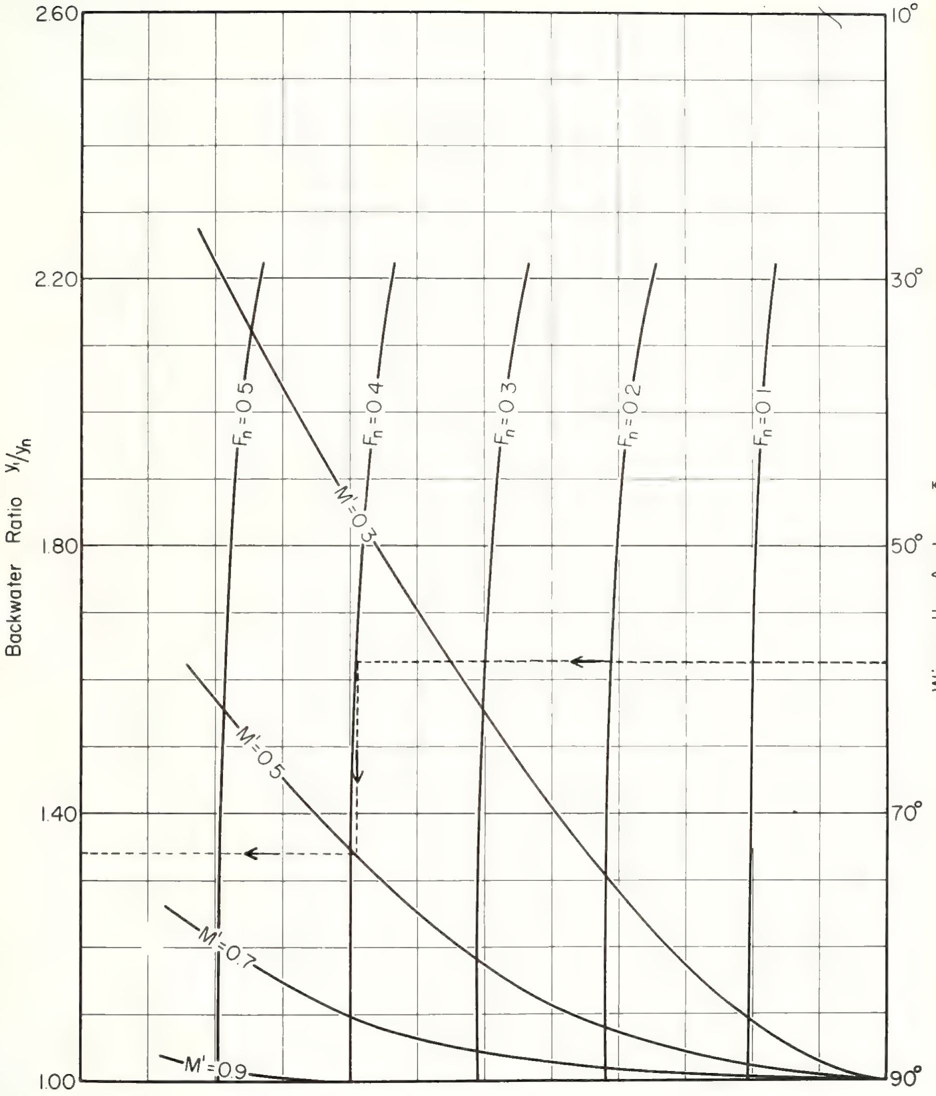
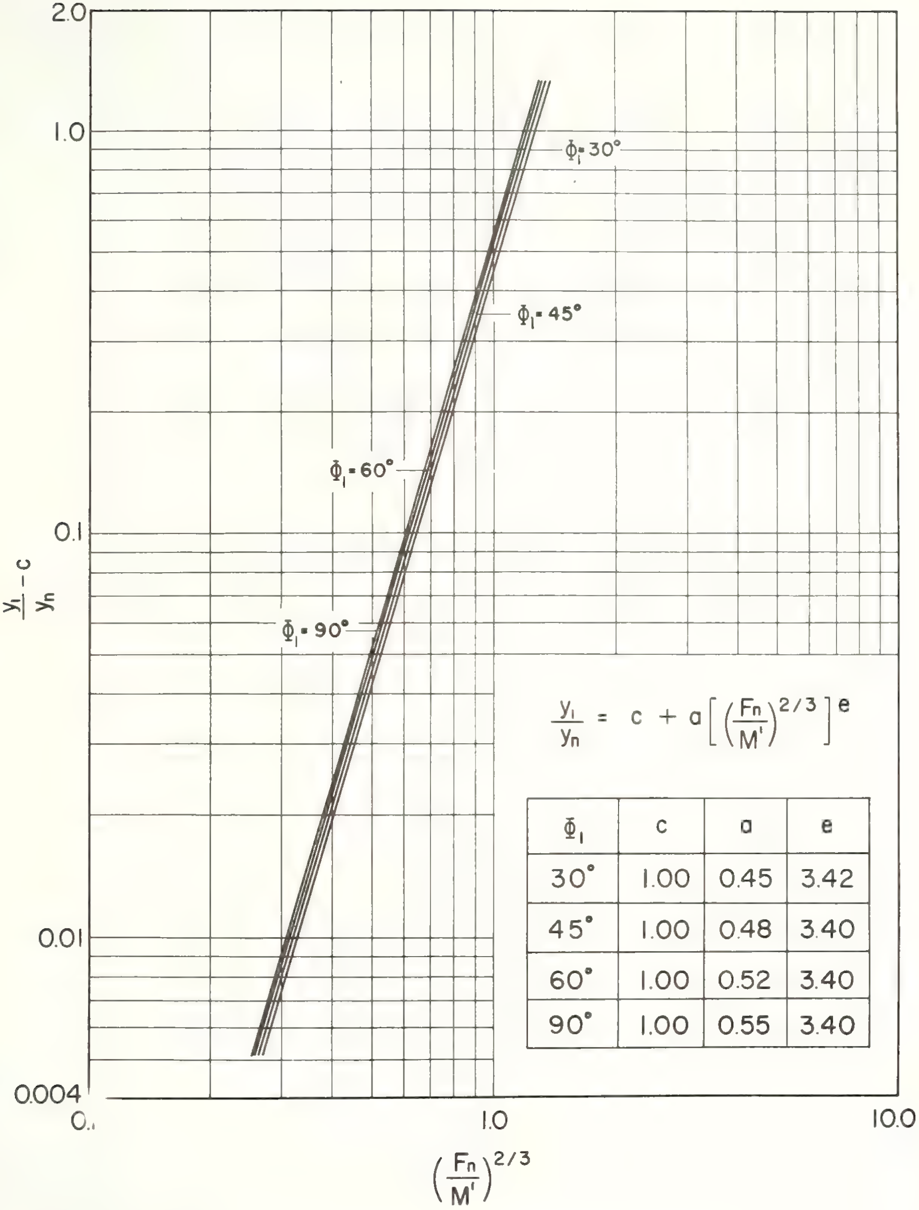


FIG. 7-4-5 BACKWATER RATIO FOR ARCH BRIDGES WITH WINGWALLS



$$\frac{y_1}{y_n} = c + a\left[\left(\frac{F_n}{M'}\right)^{2/3}\right]^e$$

Φ_1	c	a	e
30°	1.00	0.45	3.42
45°	1.00	0.48	3.40
60°	1.00	0.52	3.40
90°	1.00	0.55	3.40

FIG. 7-4-6 - GENERALIZED BACKWATER RATIO FOR ARCH BRIDGES WITH WINGWALLS

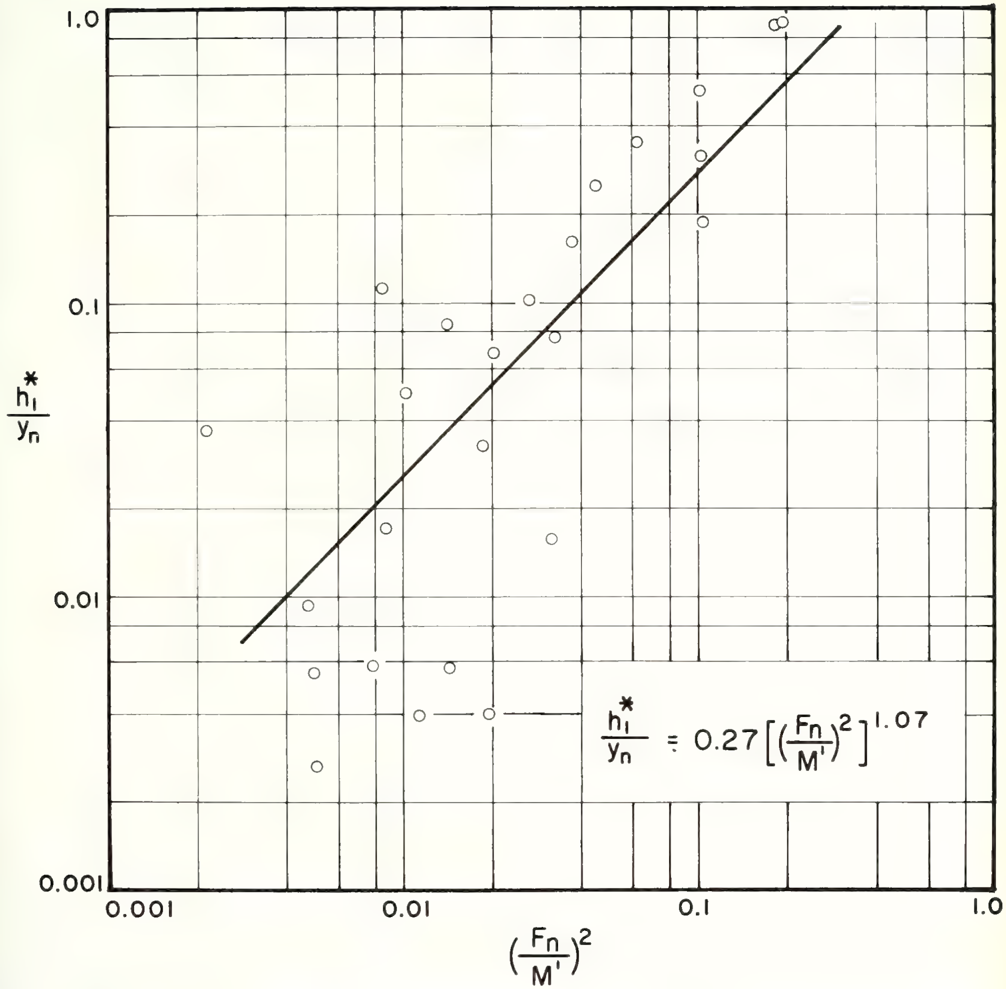


FIGURE 7-4-7 BACKWATER RATIO, GEOMETRY III

ROUGH BOUNDARY $\Phi_1 = 30°$

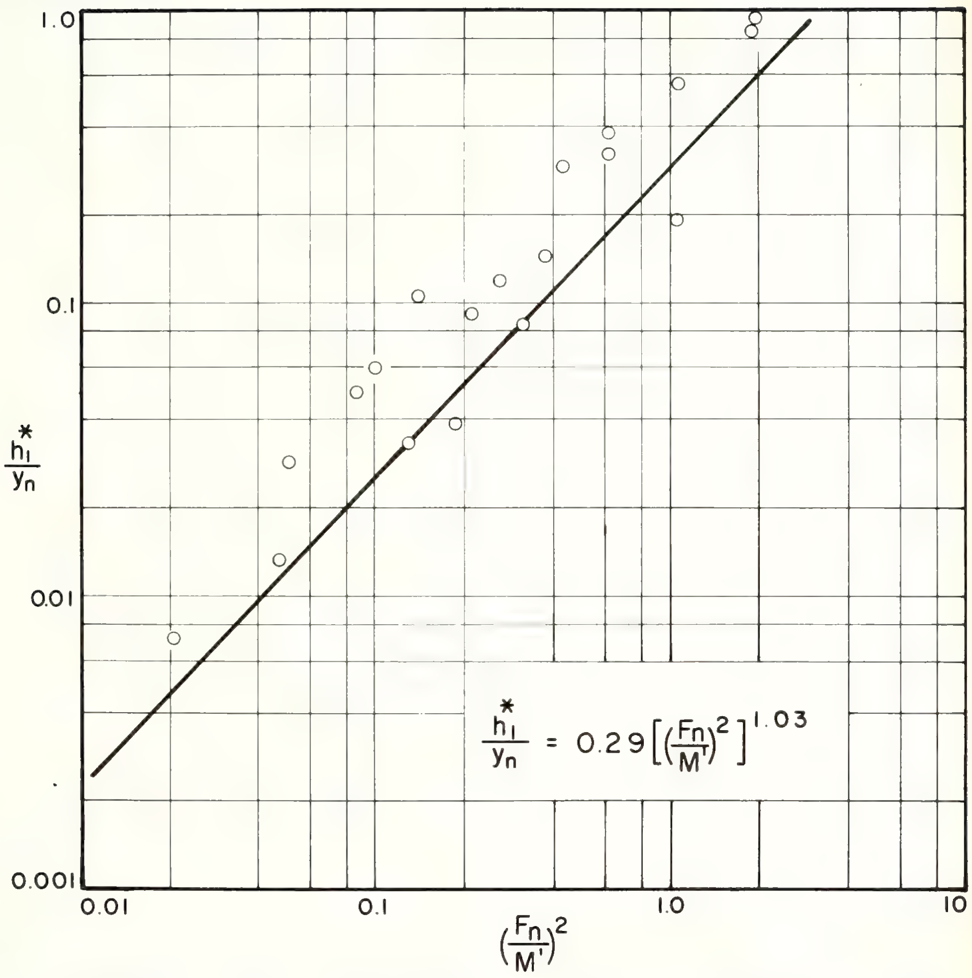


FIGURE 7-4-8 BACKWATER RATIO, GEOMETRY III

ROUGH BOUNDARY $\Phi_1 = 45°$

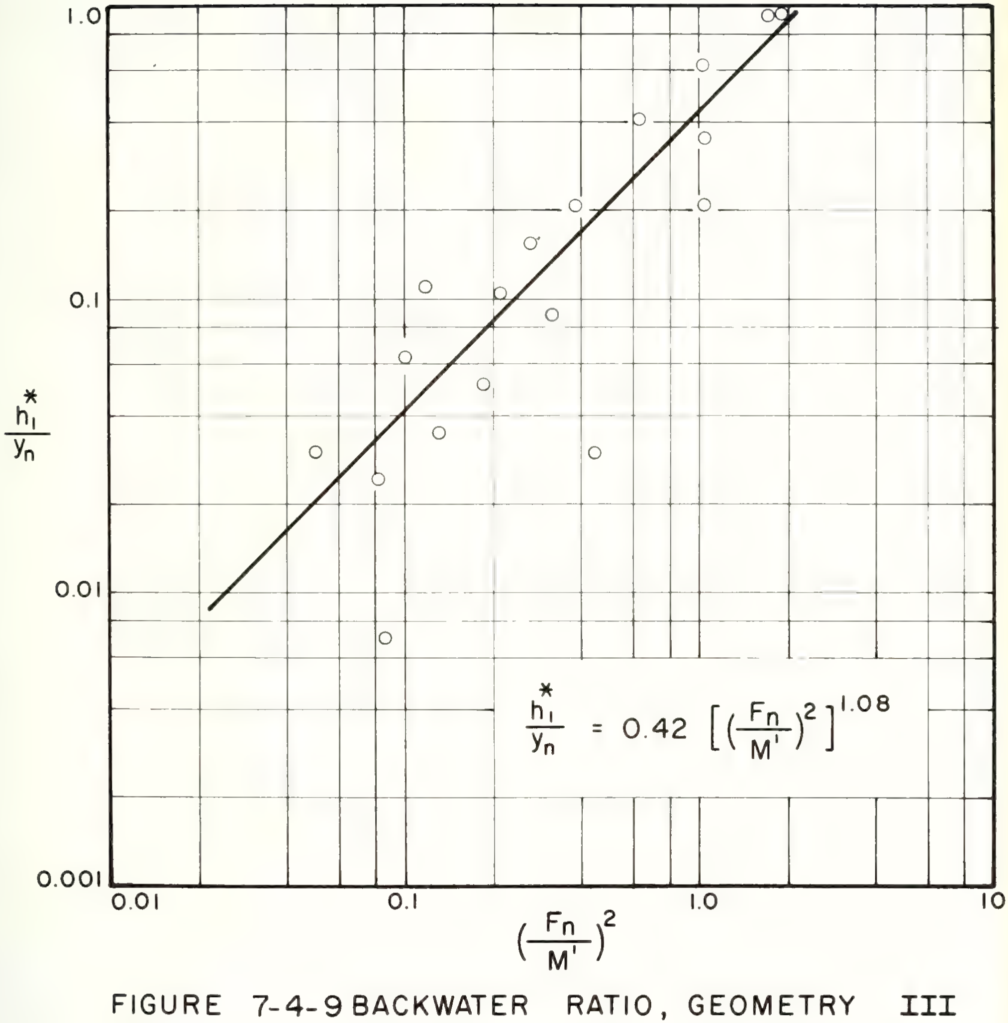


FIGURE 7-4-9 BACKWATER RATIO, GEOMETRY III ROUGH BOUNDARY $\Phi_1 = 60°$

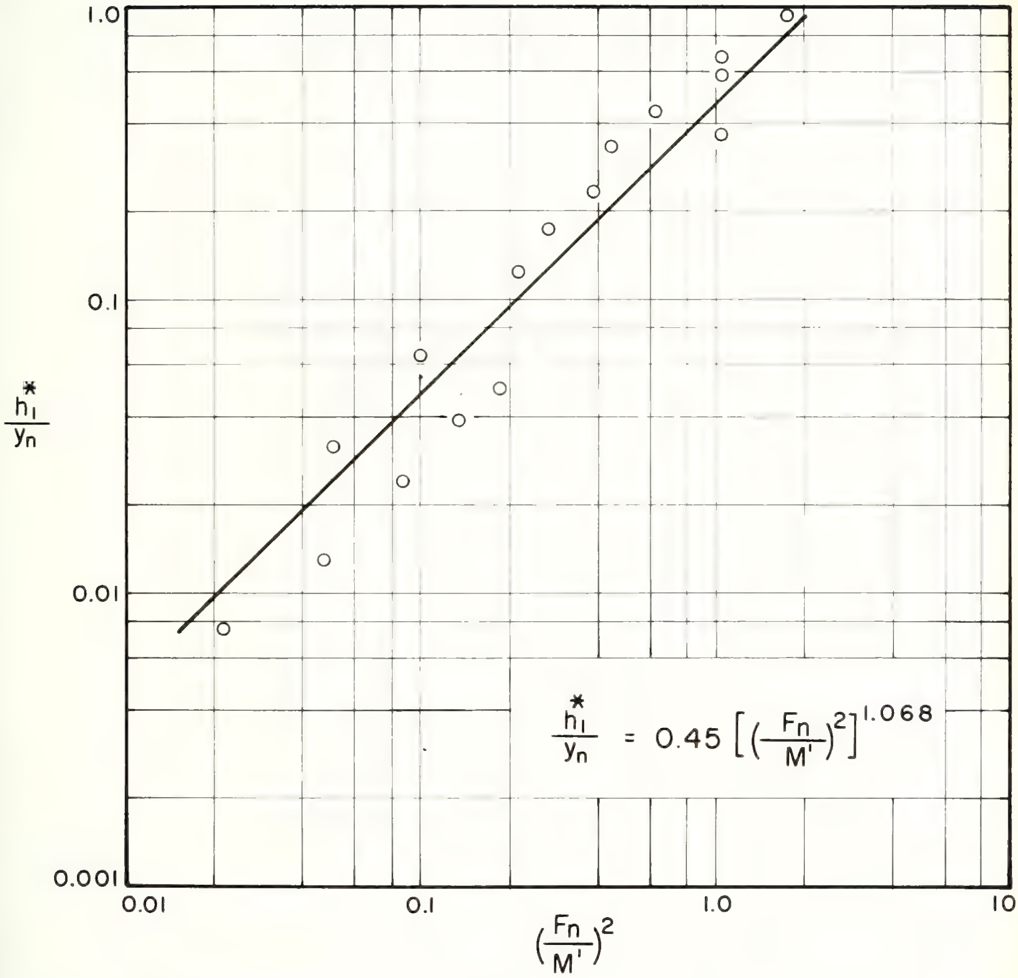


FIGURE 7-4-10 BACKWATER RATIO, GEOMETRY III ROUGH BOUNDARY $\Phi_1 = 90°$

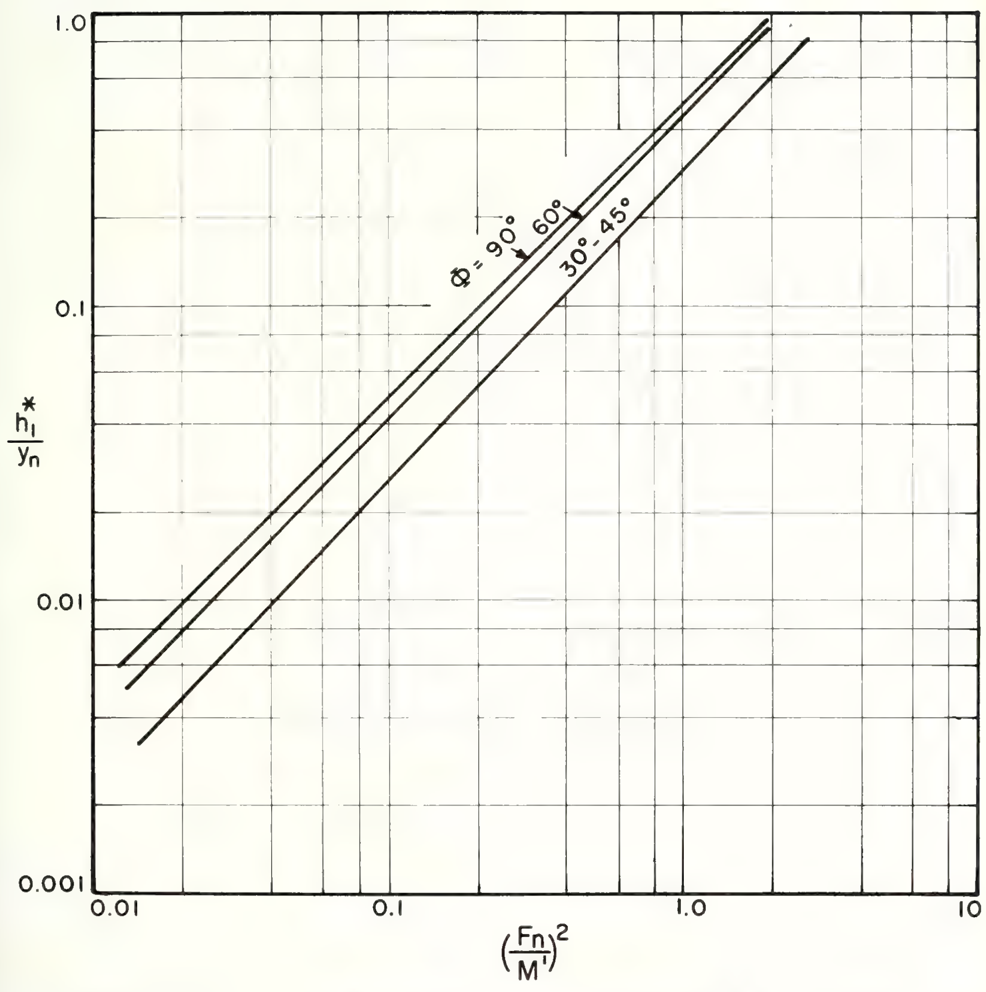


FIGURE 7-4-11 SUMMARY OF BACKWATER RATIO, GEOMETRY III, ROUGH BOUNDARY

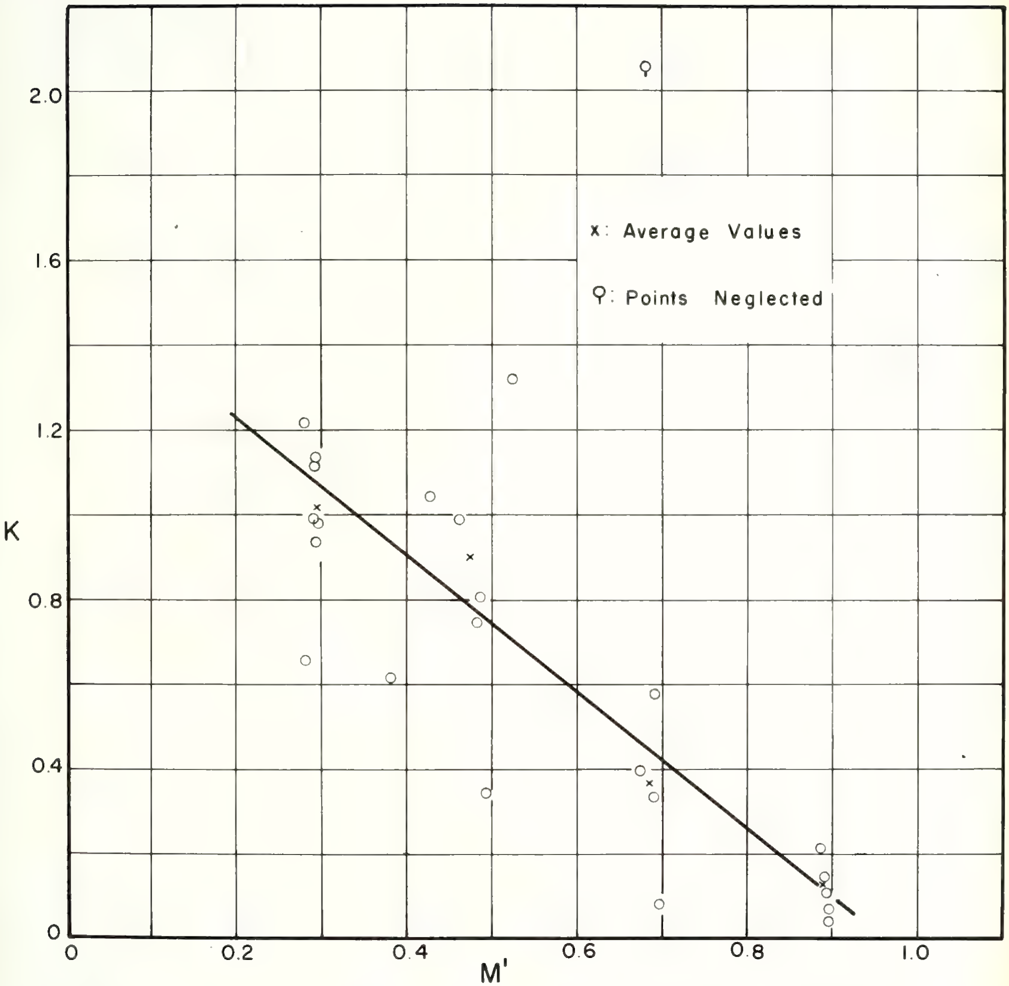


FIGURE 7-4-12 HEAD LOSS COEFFICIENT, GEOMETRY III ROUGH BOUNDARY $\Phi_1 = 30°$

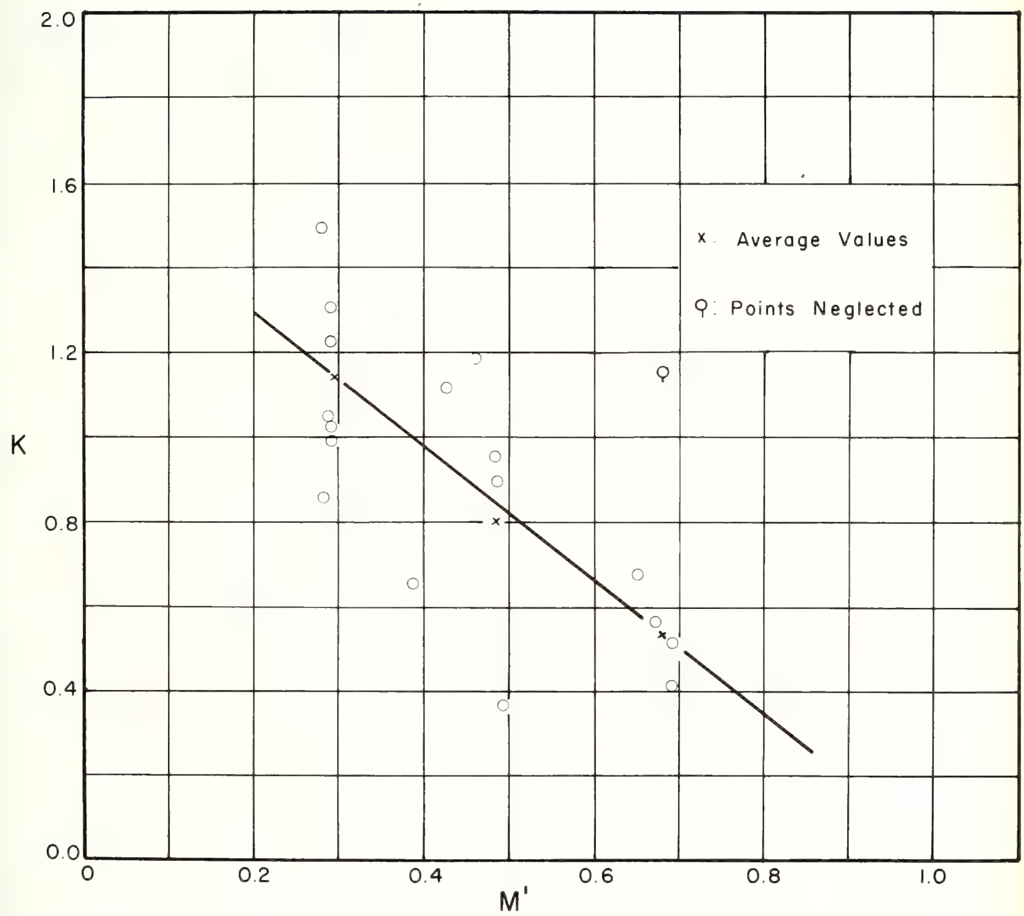


FIGURE 7-4-13 HEAD LOSS COEFFICIENT, GEMETRY III
ROUGH BOUNDARY $\Phi_1 = 45°$

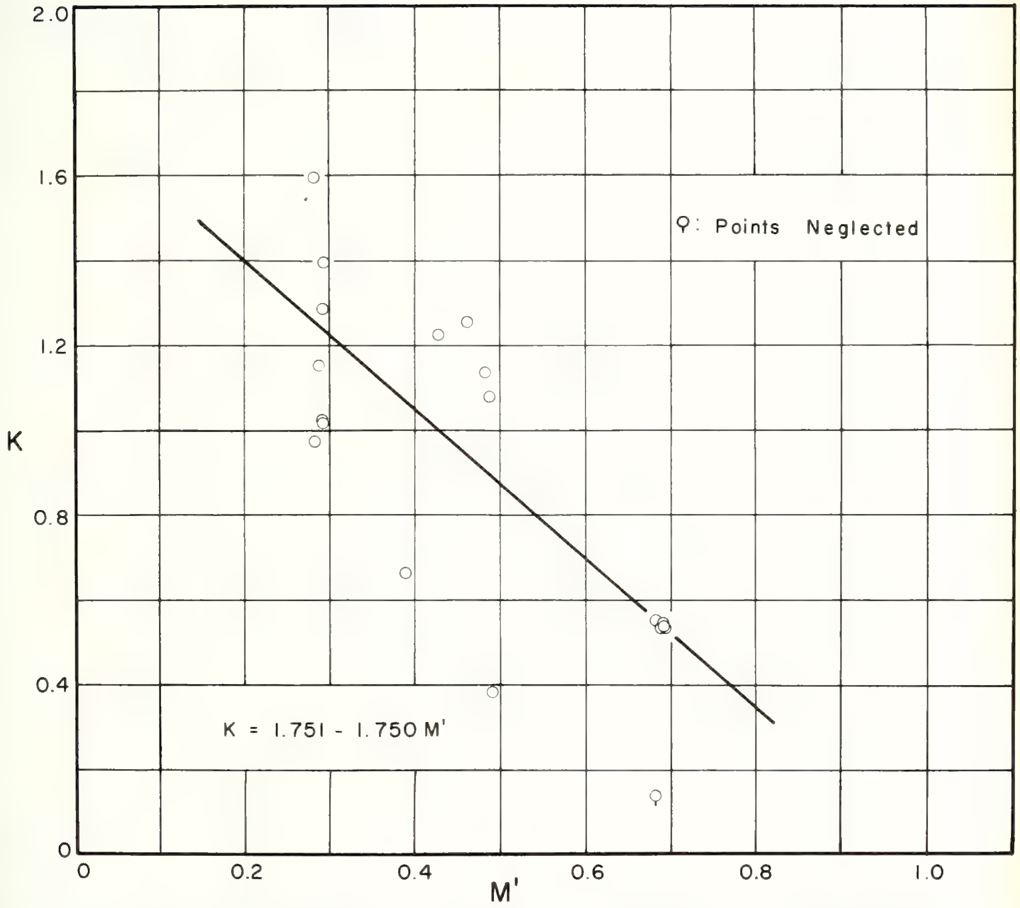


FIGURE 7-4-14 HEAD LOSS COEFFICIENT, GEOMETRY III
ROUGH BOUNDARY $\Phi_1 = 60°$

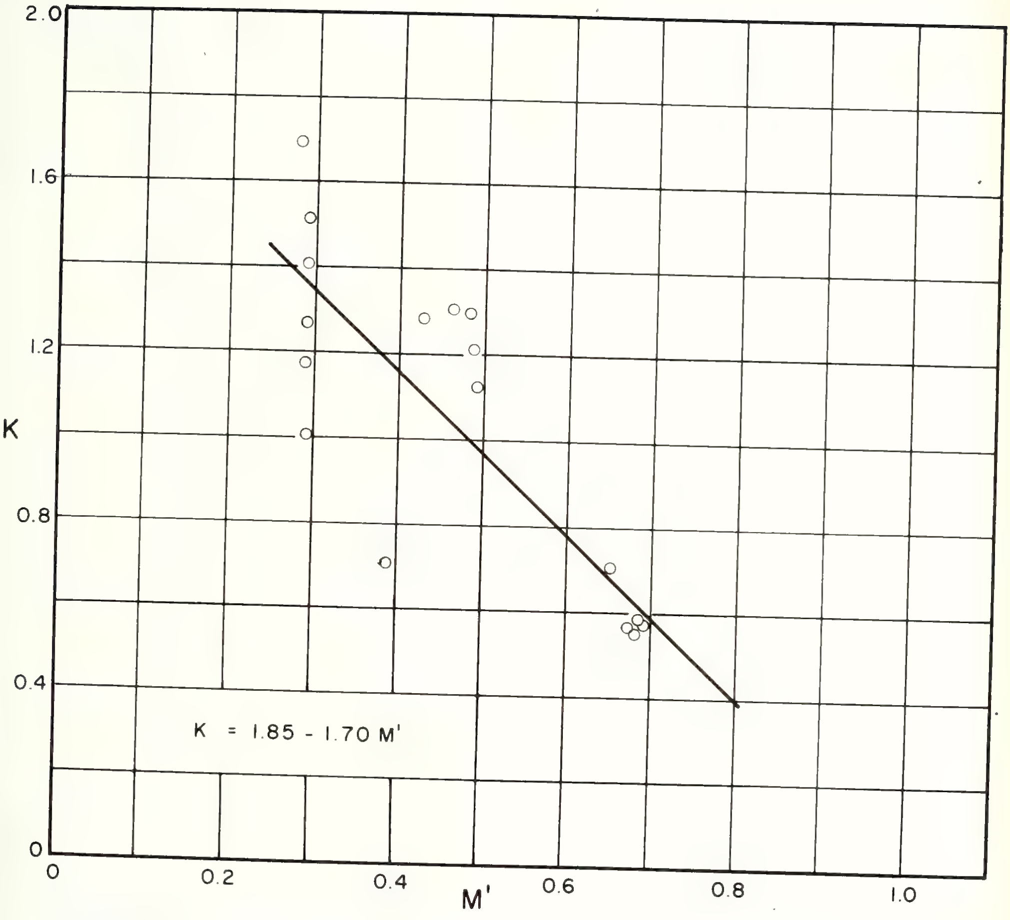


FIGURE 7-4-15 HEAD LOSS COEFFICIENT, GEOMETRY III
ROUGH BOUNDARY $\Phi_1 = 90°$

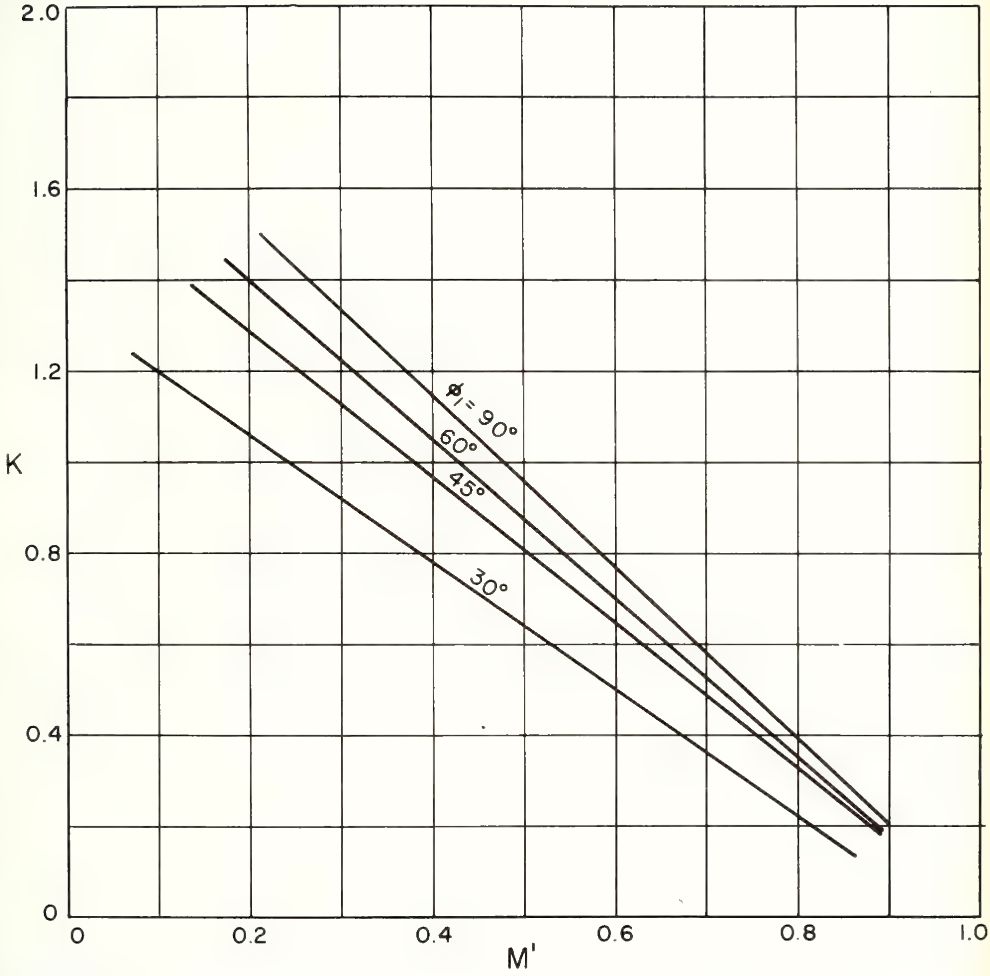


FIGURE 7-4-16 SUMMARY OF HEAD LOSS COEFFICIENTS GEOMETRY III, ROUGH BOUNDARIES

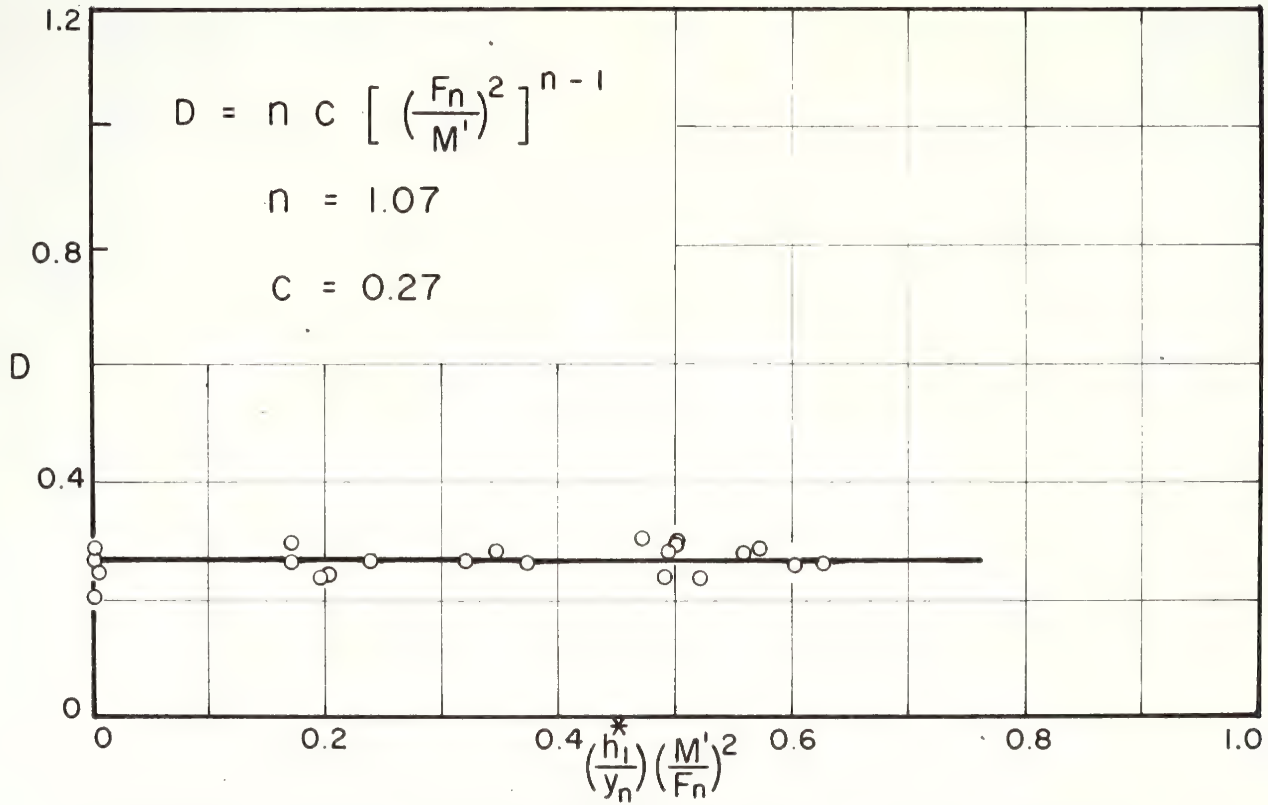


FIGURE 7-4-17 BACKWATER RATIO COEFFICIENT, GEOMETRY III, ROUGH BOUNDARY $\Phi_1 = 30°$

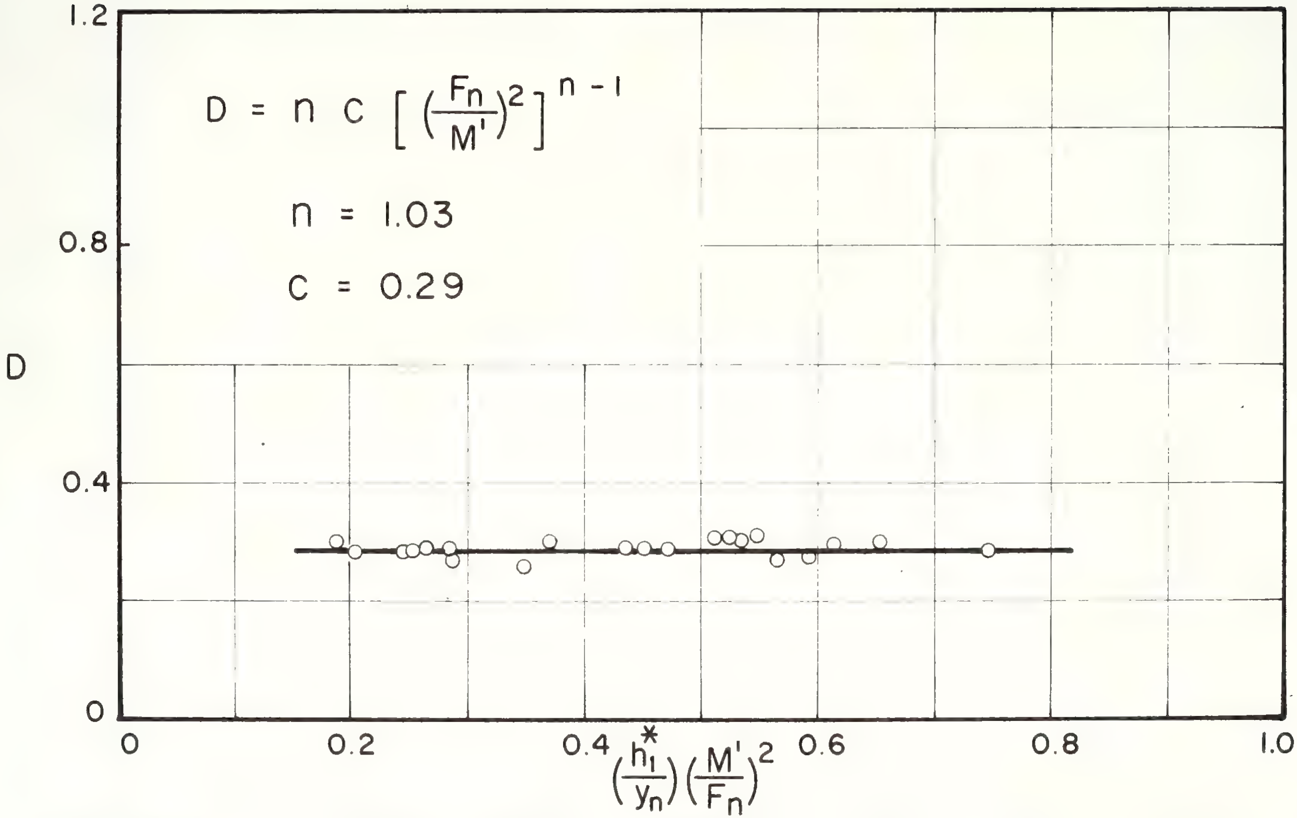


FIGURE 7-4-18 BACKWATER RATIO COEFFICIENT, GEOMETRY III ROUGH BOUNDARY $\Phi_1 = 45°$

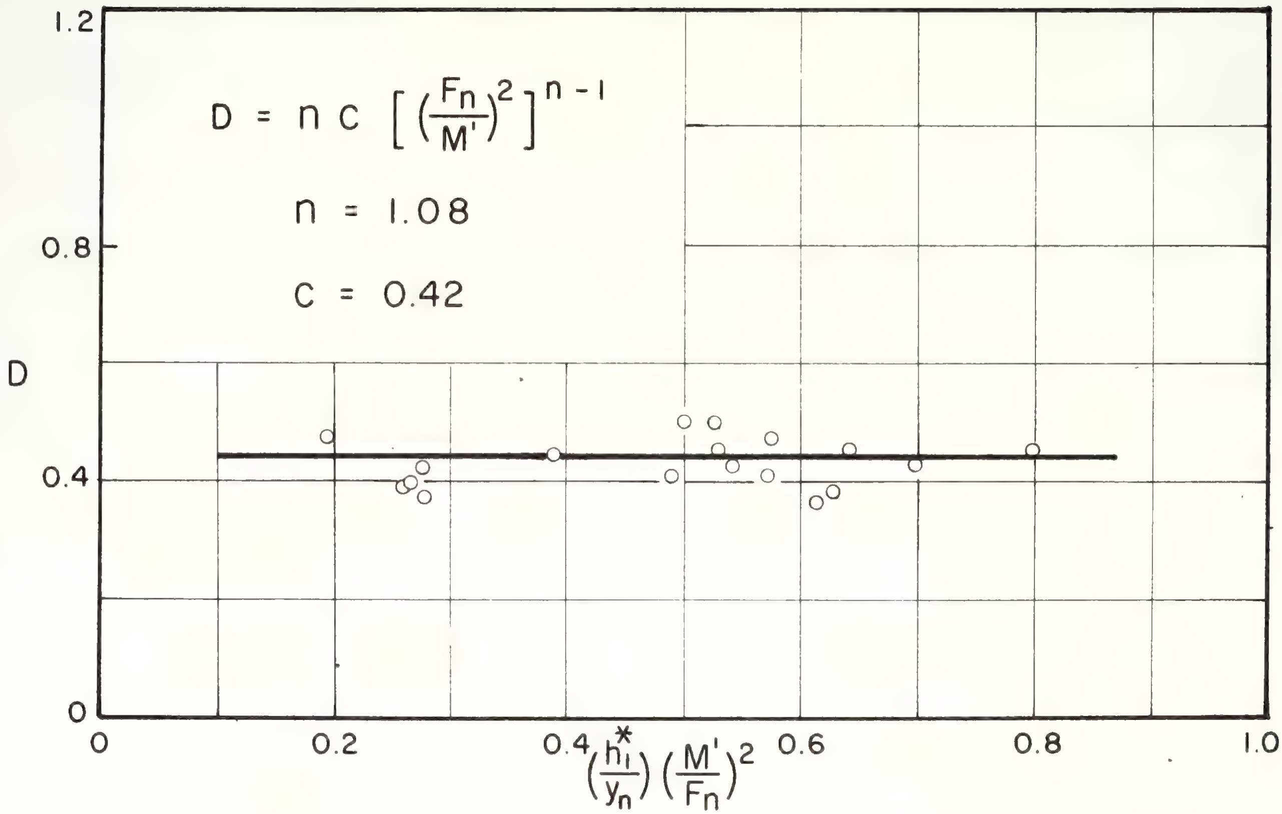


FIGURE 7-4-19 BACKWATER RATIO COEFFICIENT, GEOMETRY III, ROUGH BOUNDARY $\Phi_1 = 60°$

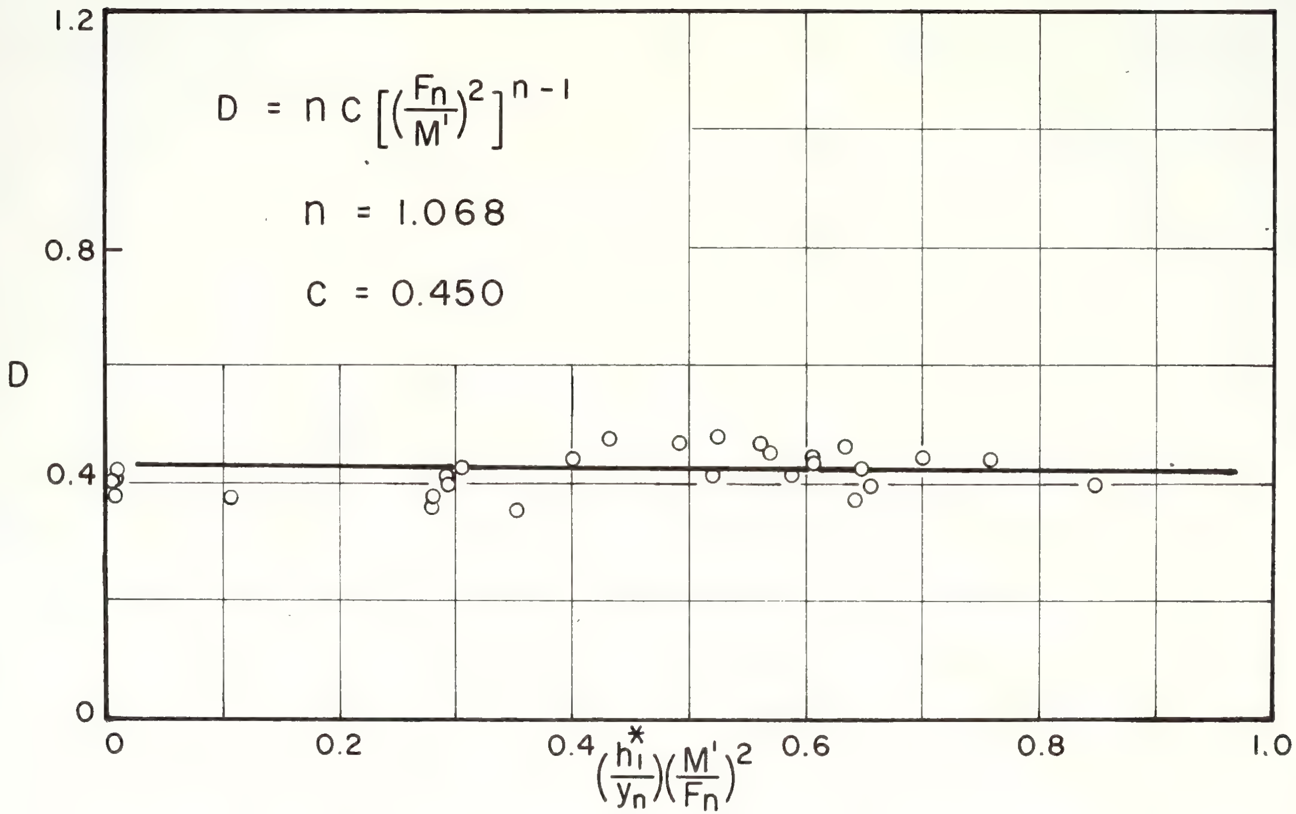


FIGURE 7-4-20 BACKWATER RATIO COEFFICIENT, GEOMETRY III, ROUGH BOUNDARY $\Phi_1 = 90°$

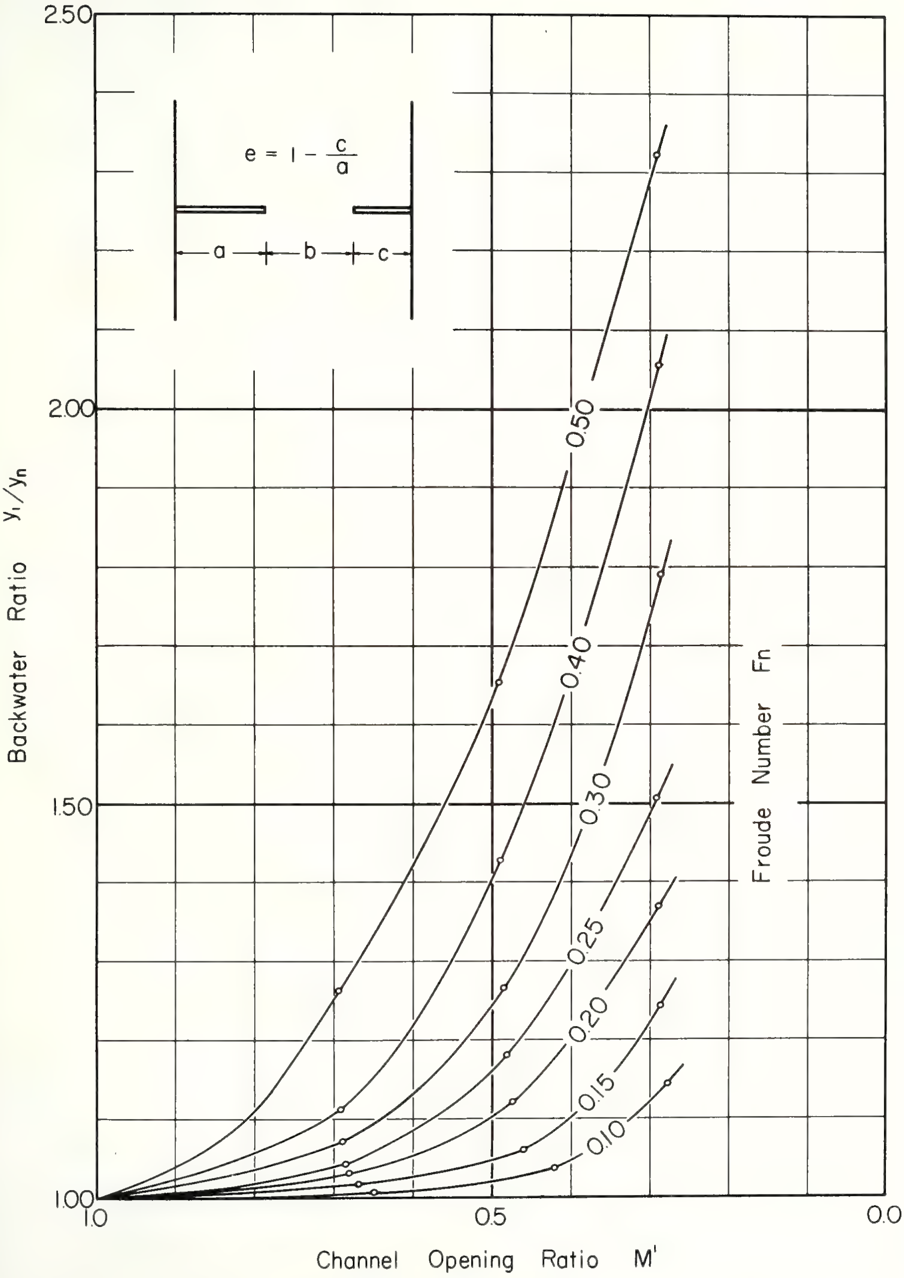


FIG. 7-5-1 BACKWATER RATIO FOR ECCENTRIC ARCH BRIDGES

e = 0

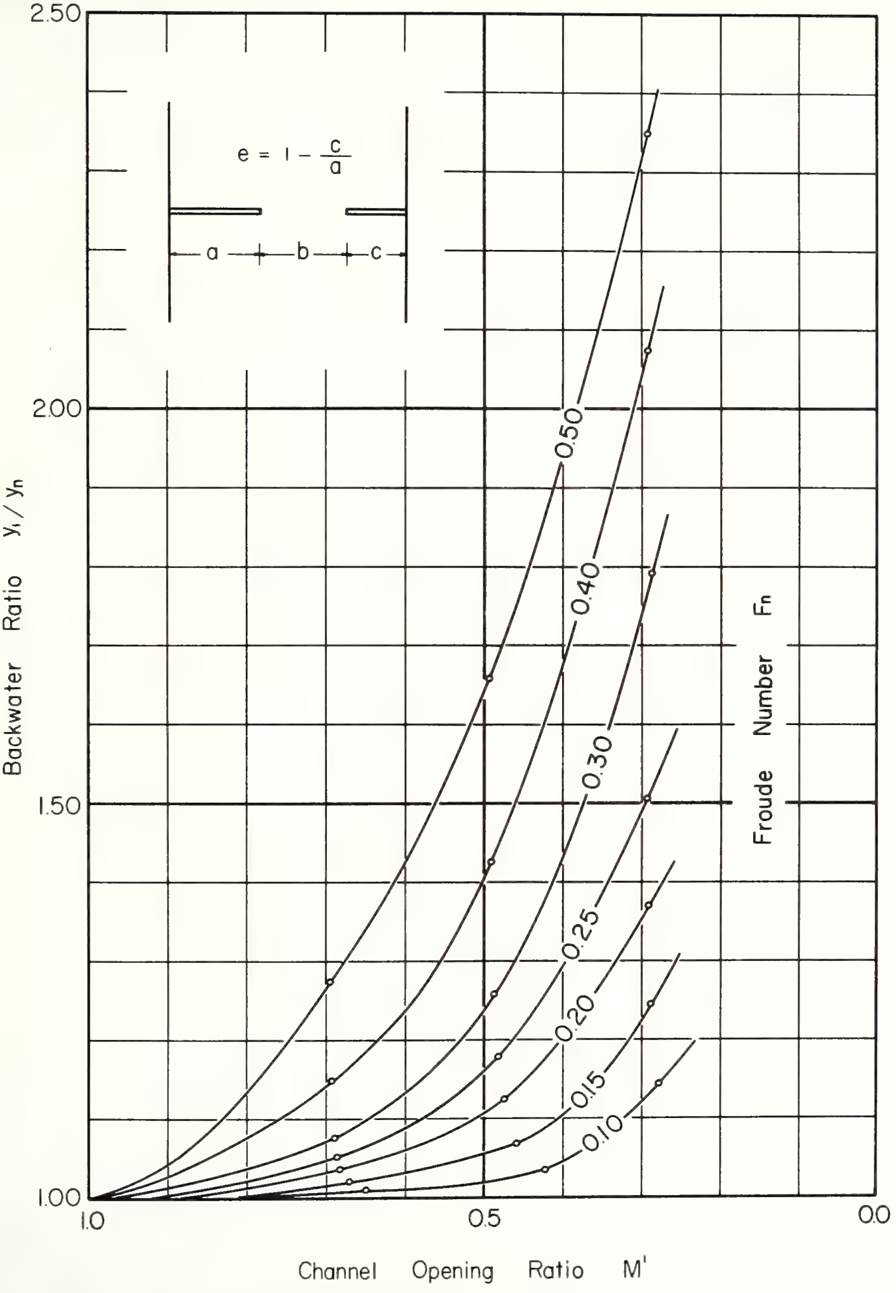


FIG. 7-5-2 - BACKWATER RATIO FOR ECCENTRIC ARCH BRIDGES

e = .80

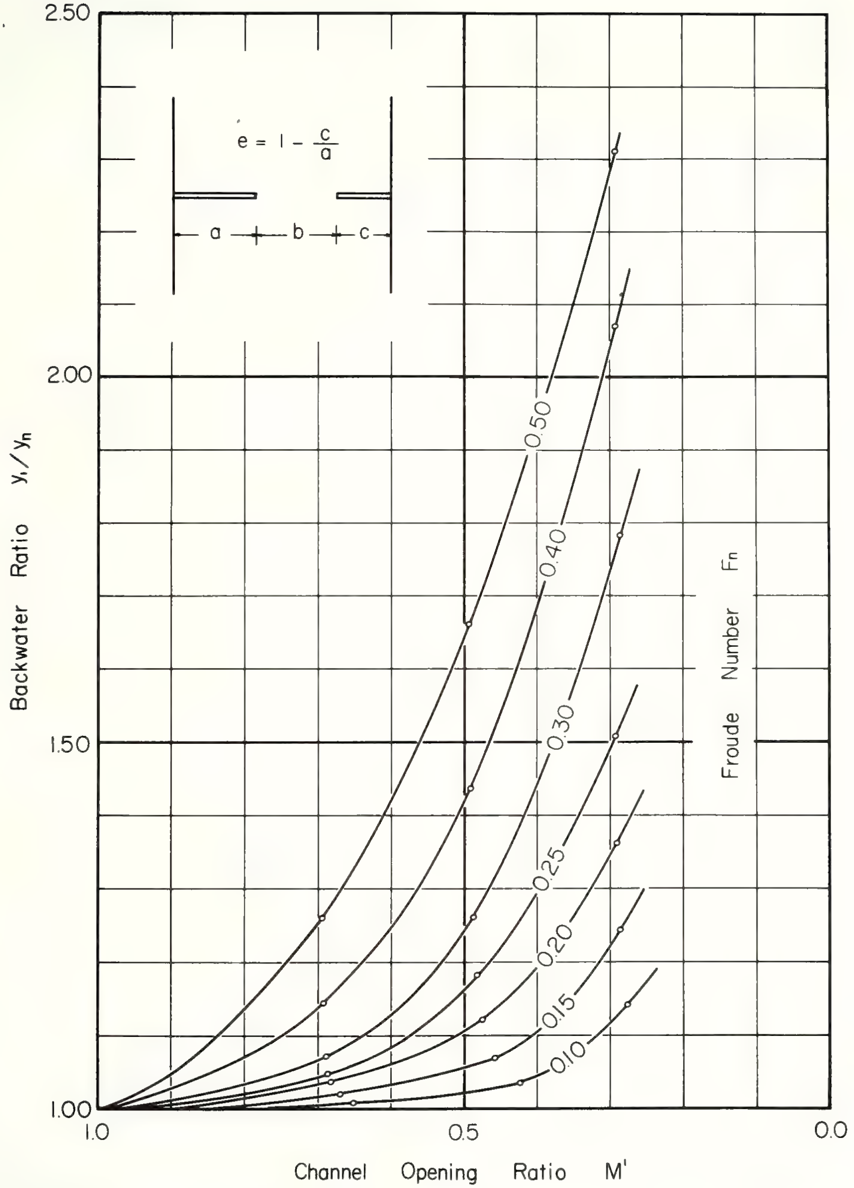


FIG. 7-5-3 - BACKWATER RATIO FOR ECCENTRIC ARCH BRIDGES

e = .85

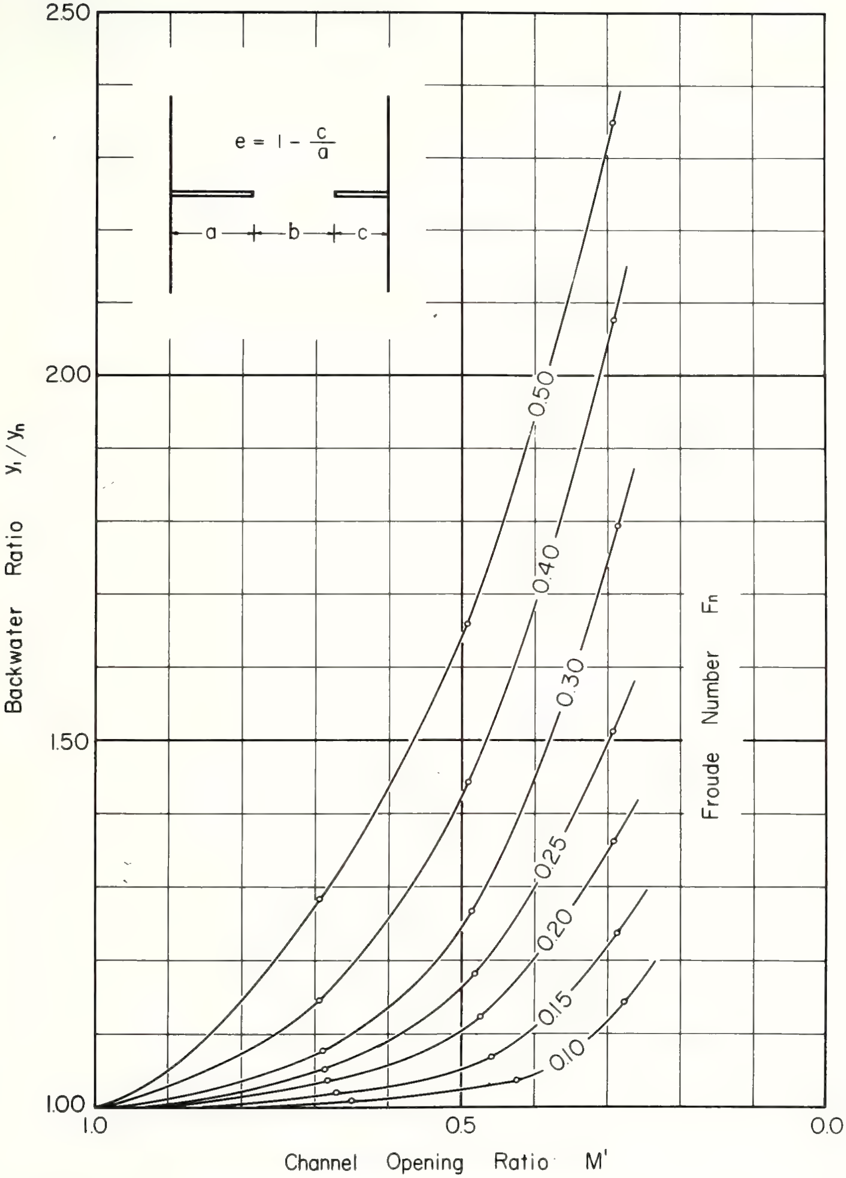


FIG. 7-5-4 BACKWATER RATIO FOR ECCENTRIC ARCH BRIDGES

e = .90

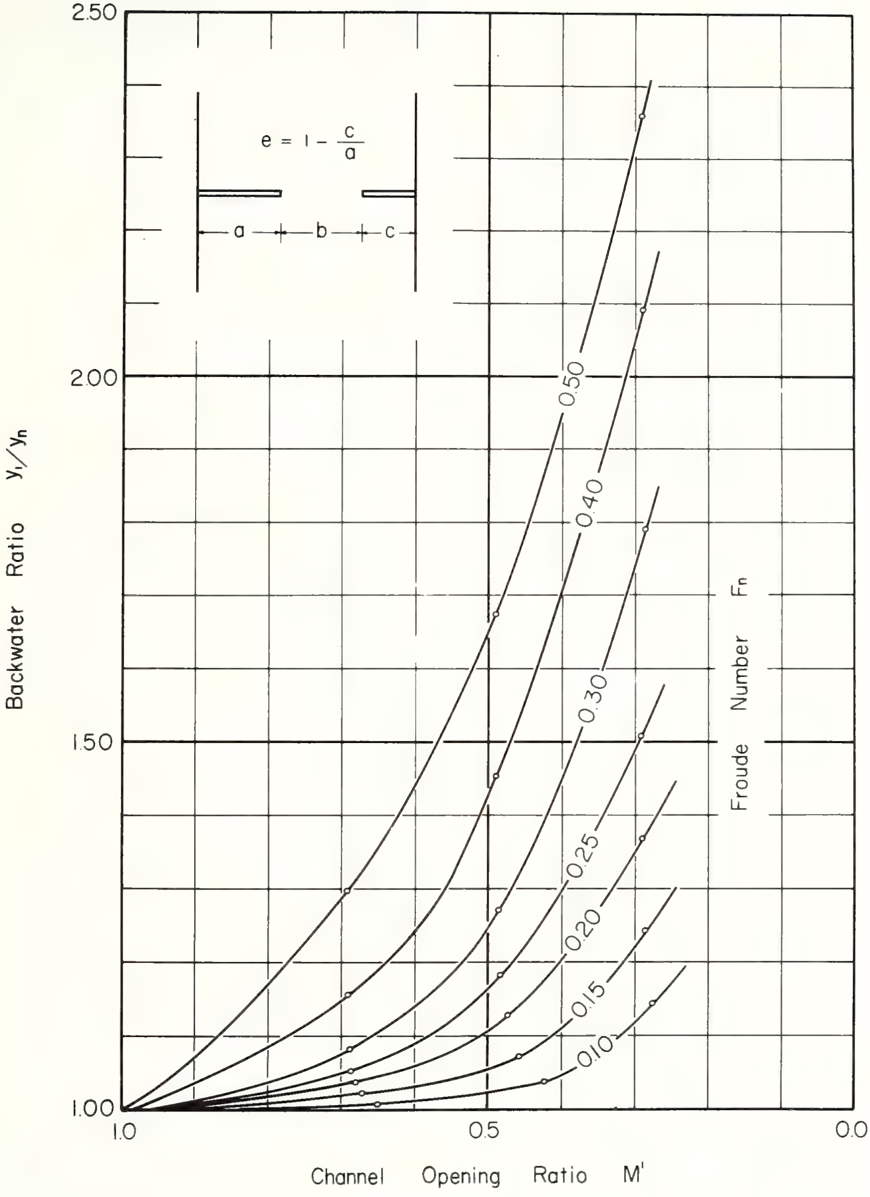


FIG. 7-5-5 - BACKWATER RATIO FOR ECCENTRIC ARCH BRIDGES

e = .95

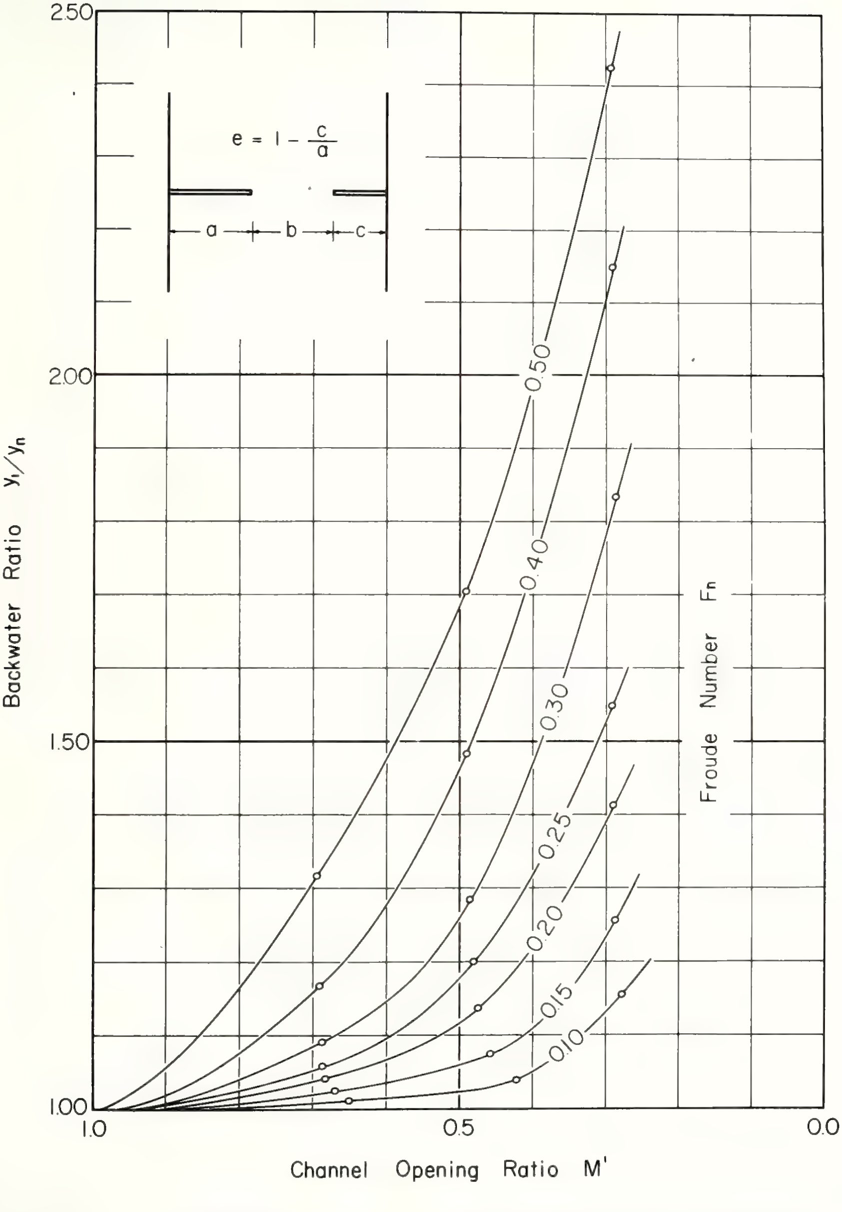


FIG. 7-5-6 - BACKWATER RATIO FOR ECCENTRIC ARCH BRIDGES

e = 1.00

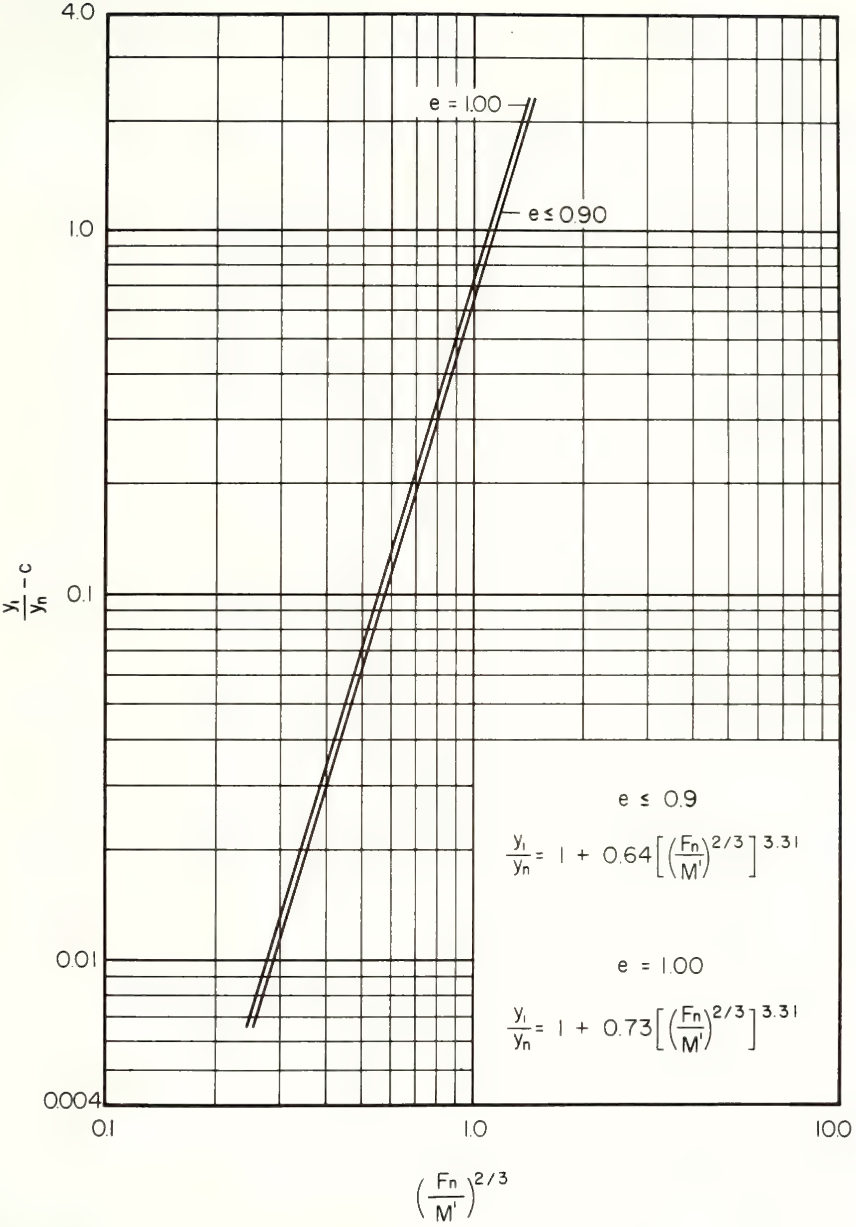


FIG. 7-5-7 - GENERALIZED BACKWATER RATIO FOR ECCENTRIC ARCH BRIDGE

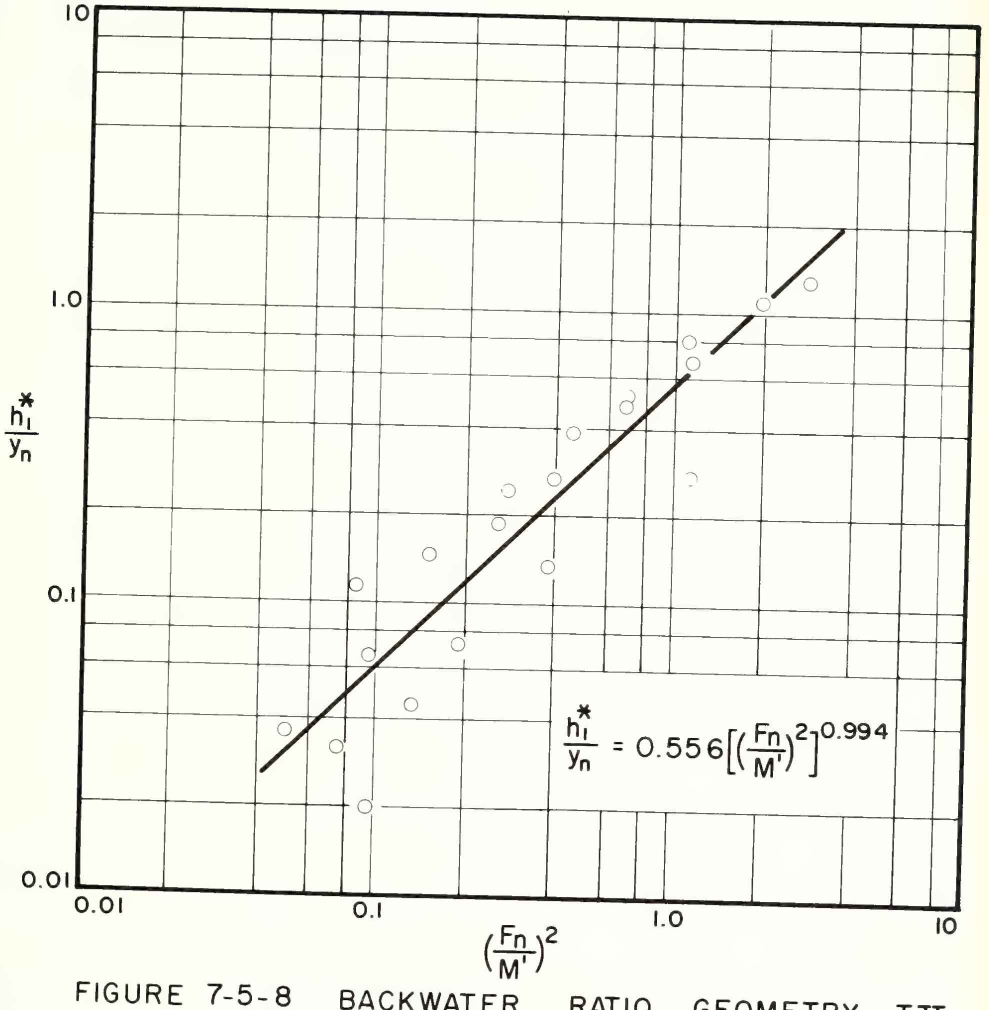


FIGURE 7-5-8 BACKWATER RATIO, GEOMETRY IV
ROUGH BOUNDARY $e = 0.0$

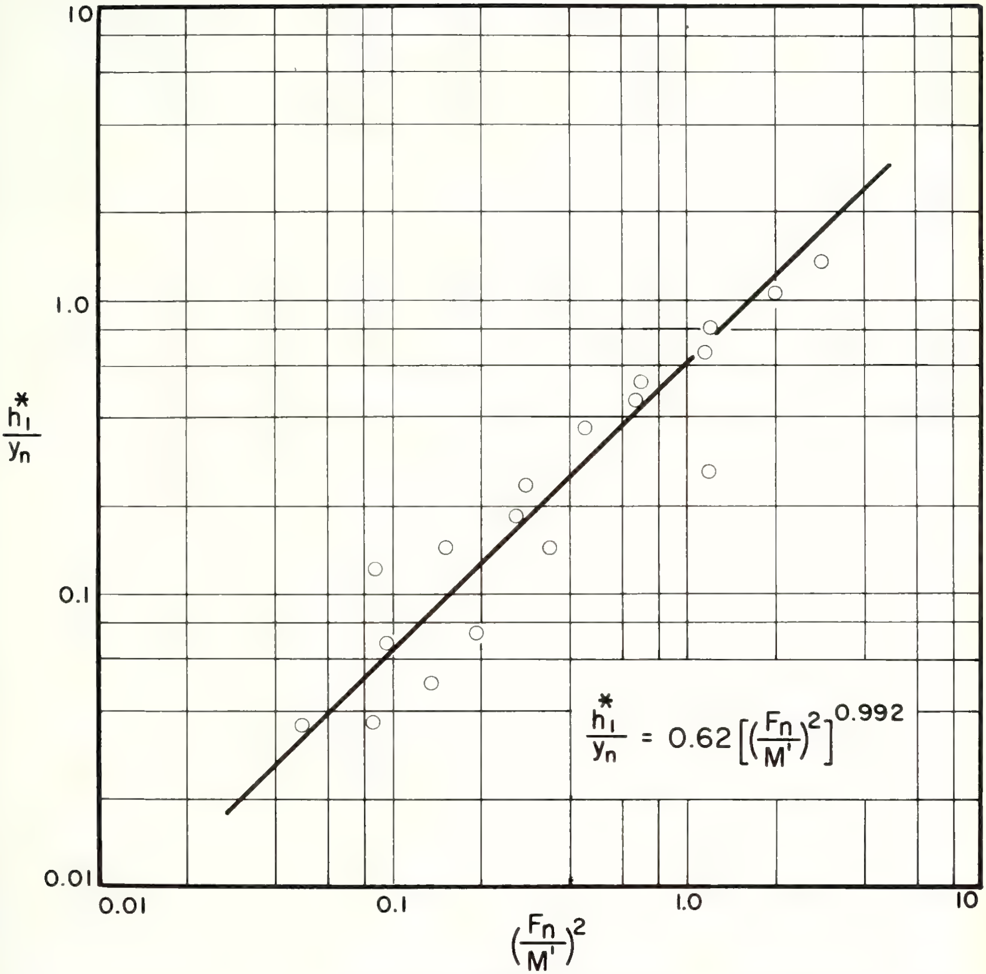


FIGURE 7-5-9 BACKWATER RATIO, GEOMETRY IV

ROUGH BOUNDARY e = 0.8

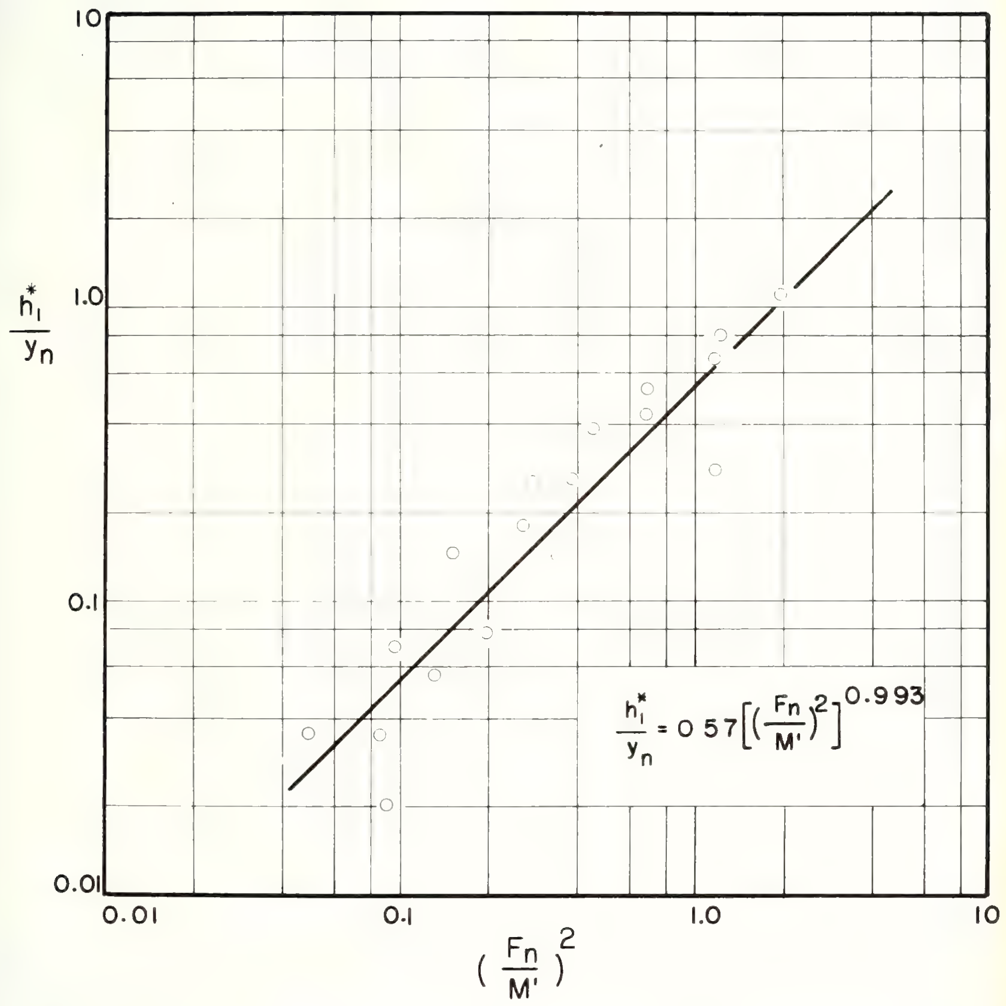


FIGURE 7-5-10 BACKWATER RATIO GEOMETRY IV

ROUGH BOUNDARY $e = 0.85$

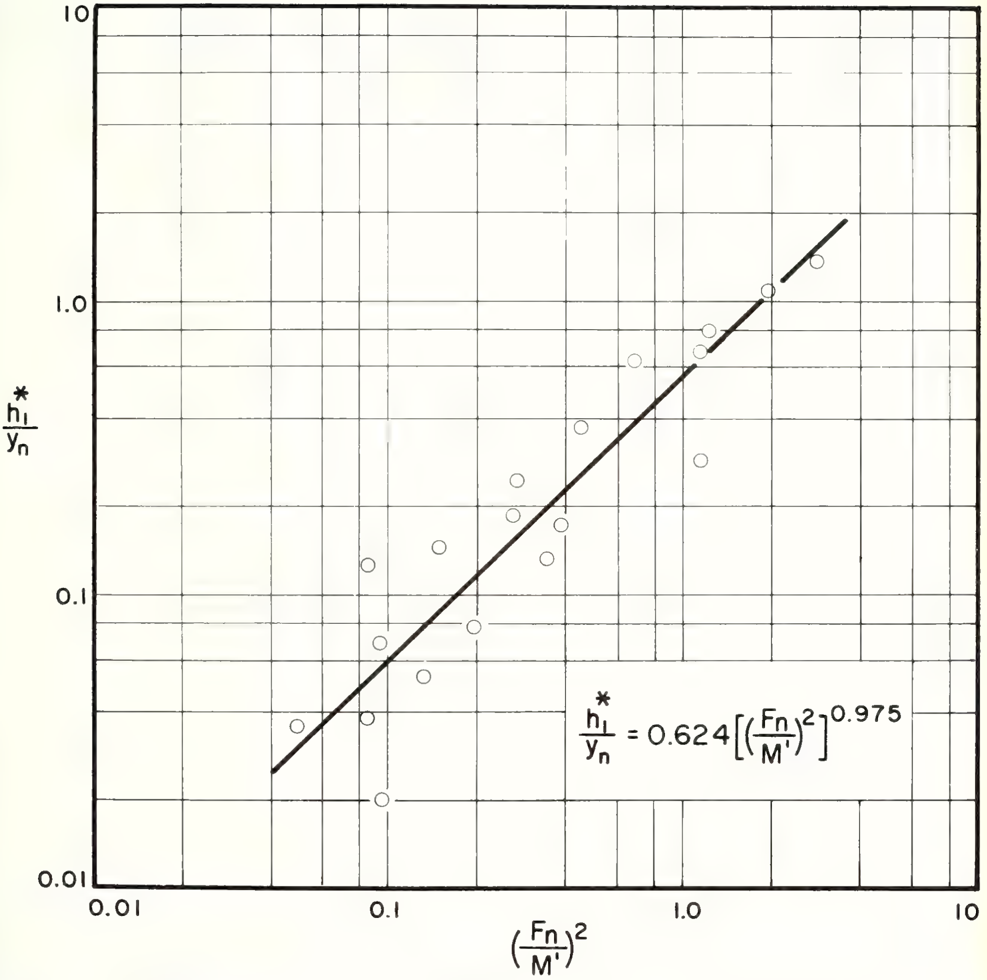


FIGURE 7-5-11 BACKWATER RATIO, GEOMETRY IV

ROUGH BOUNDARY $e = 0.9$

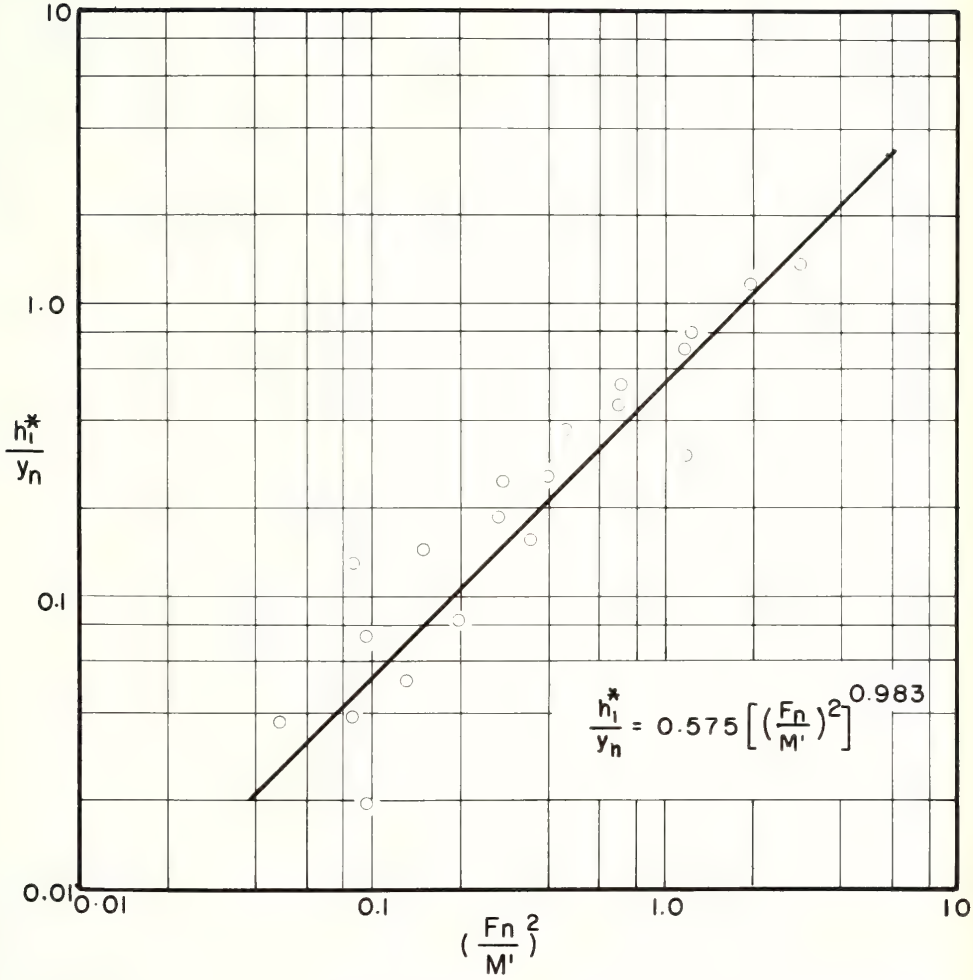


FIGURE 7-5-12 BACKWATER RATIO GEOMETRY IV

ROUGH BOUNDARY e = 0.95

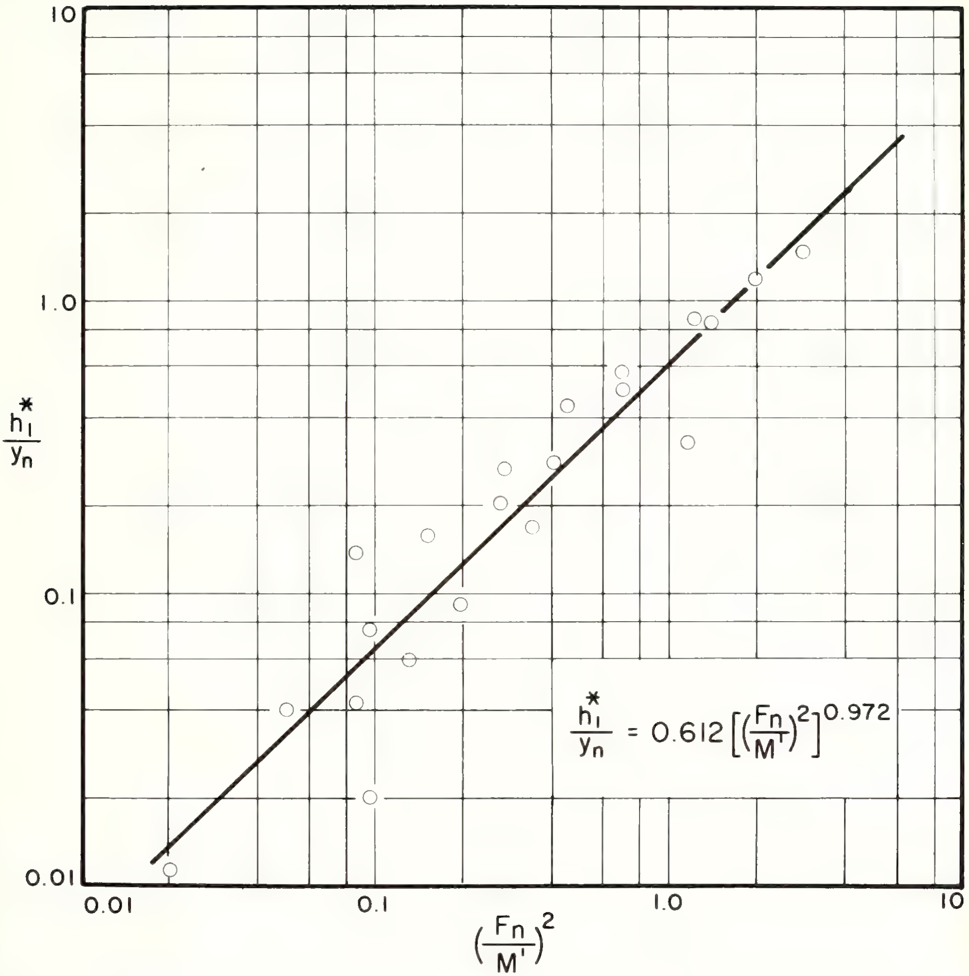


FIGURE 7-5-13 BACKWATER RATIO, GEOMETRY IV
ROUGH BOUNDARY e = 1.0

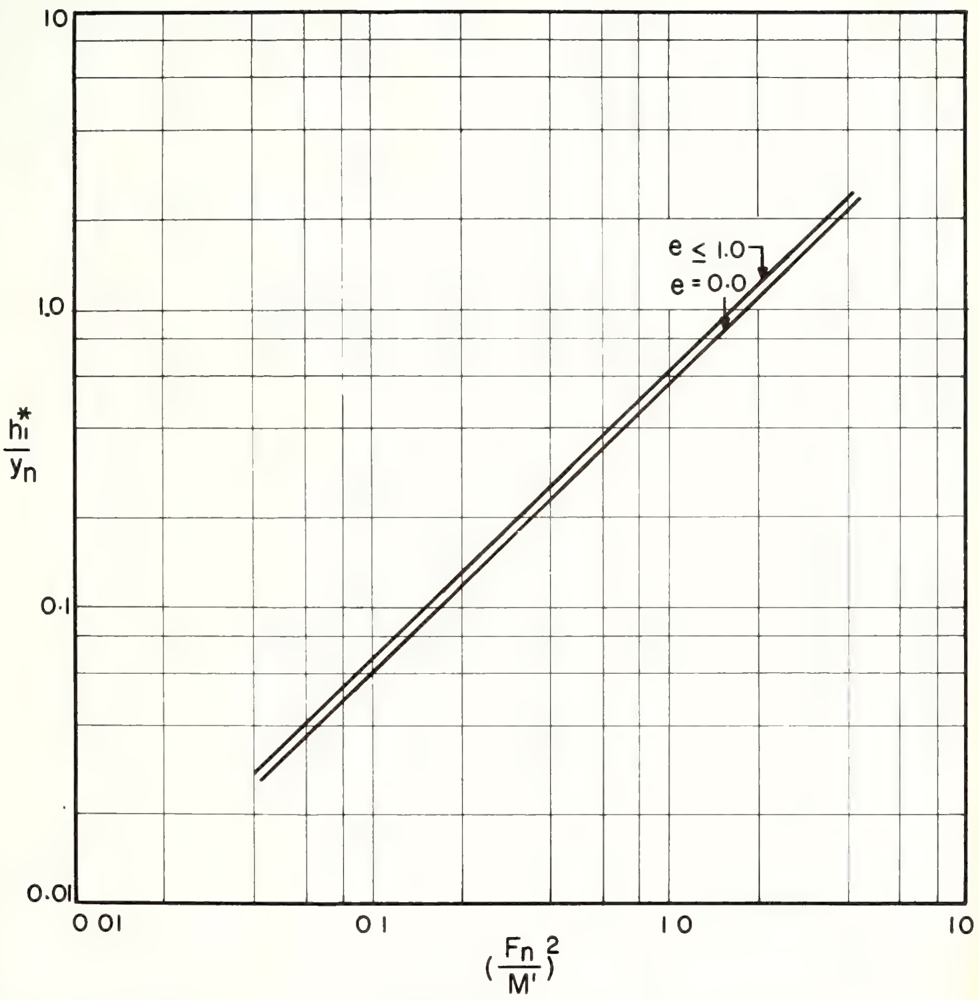


FIGURE 7-5-14 SUMMARY OF BACKWATER RATIO

GEOMETRY IV ROUGH BOUNDARY

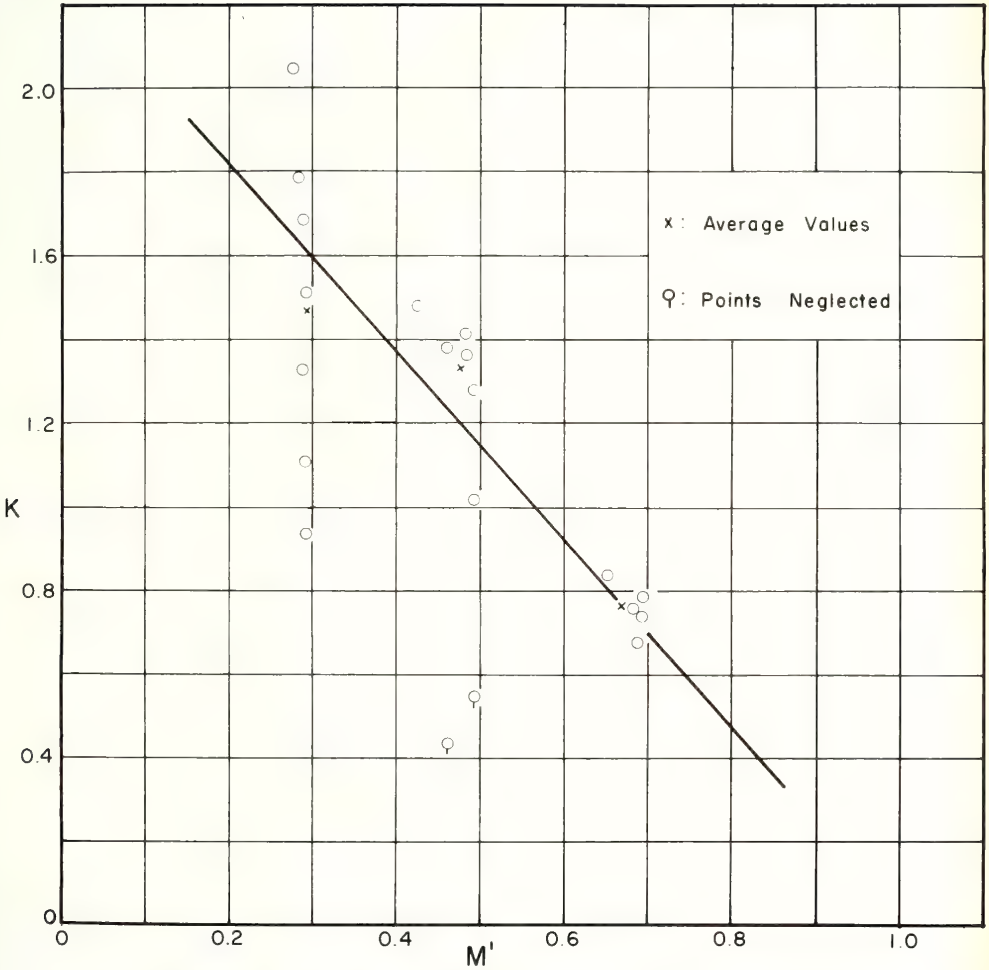


FIGURE 7-5-15 HEAD LOSS COEFFICIENT, GEOMETRY IV
ROUGH BOUNDARY e = 0.00

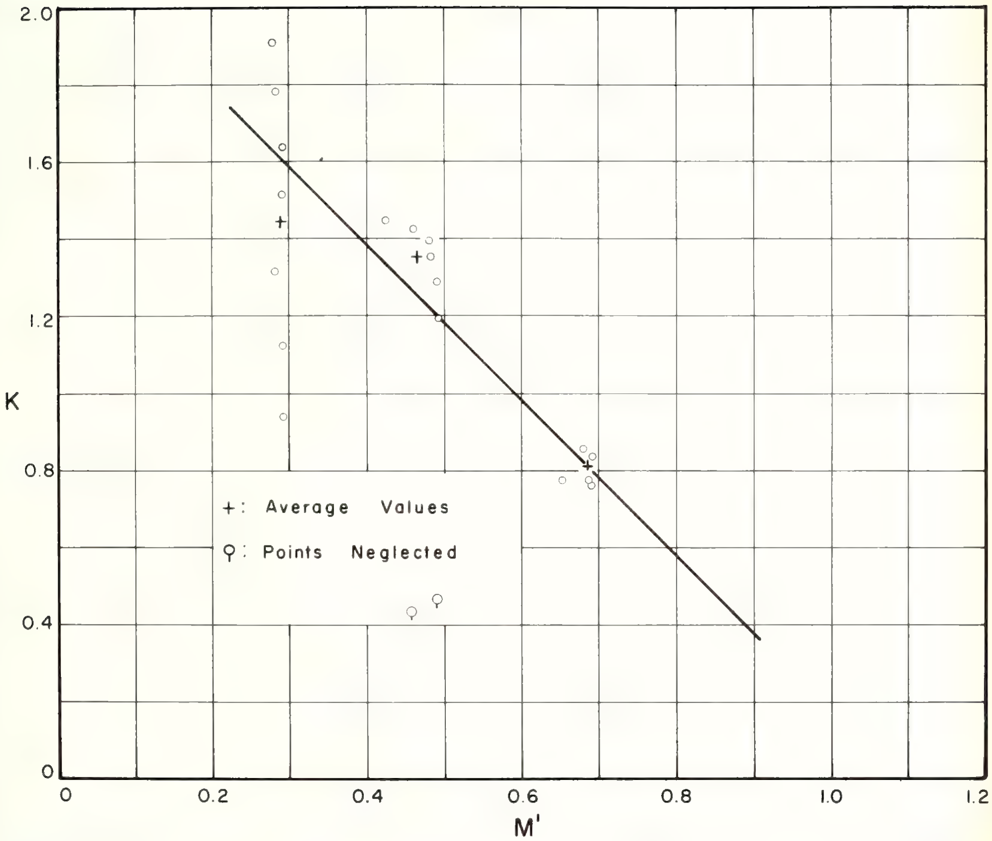


FIGURE 7-5-16 HEAD LOSS COEFFICIENT, GEOMETRY IV
ROUGH BOUNDARY e = 0·8

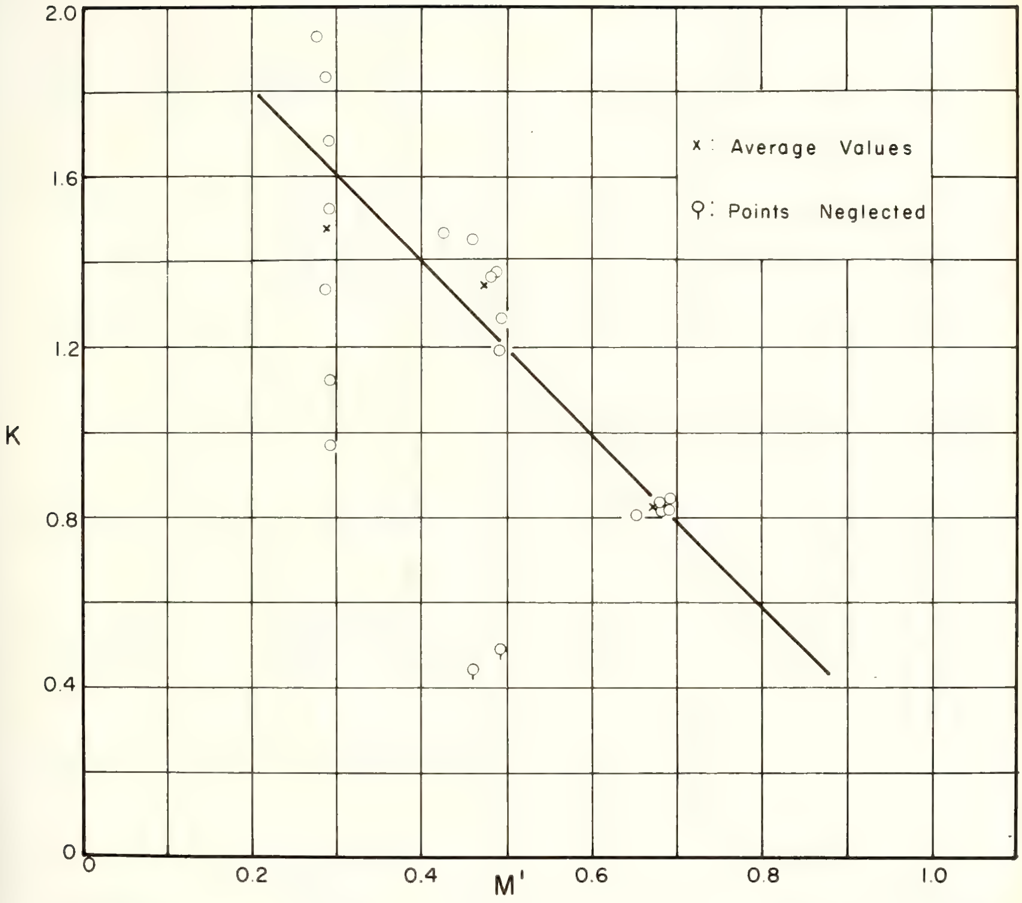


FIGURE 7-5-17 HEAD LOSS COEFFICIENT, GEOMETRY IV
ROUGH BOUNDARY e = 0.85

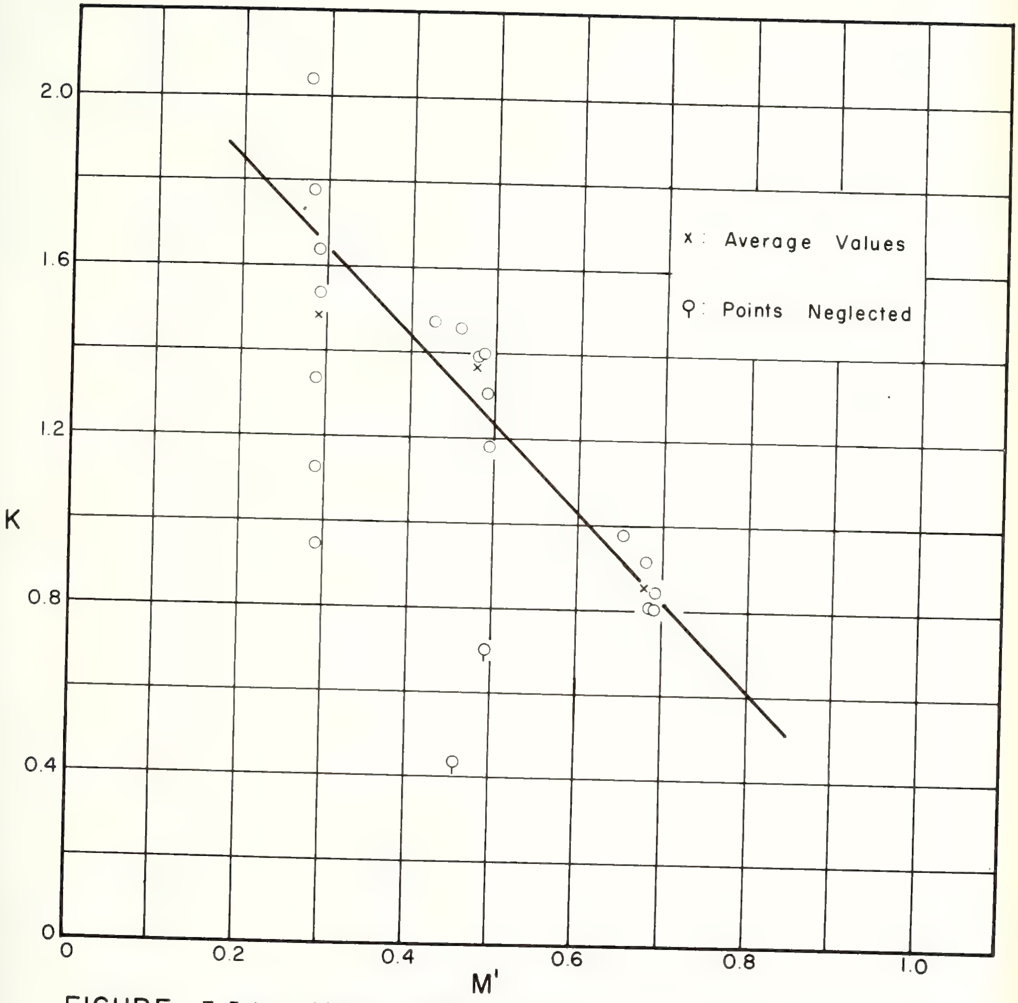


FIGURE 7-5-18 HEAD LOSS COEFFICIENT, GEOMETRY IV ROUGH BOUNDARY e = 0.9

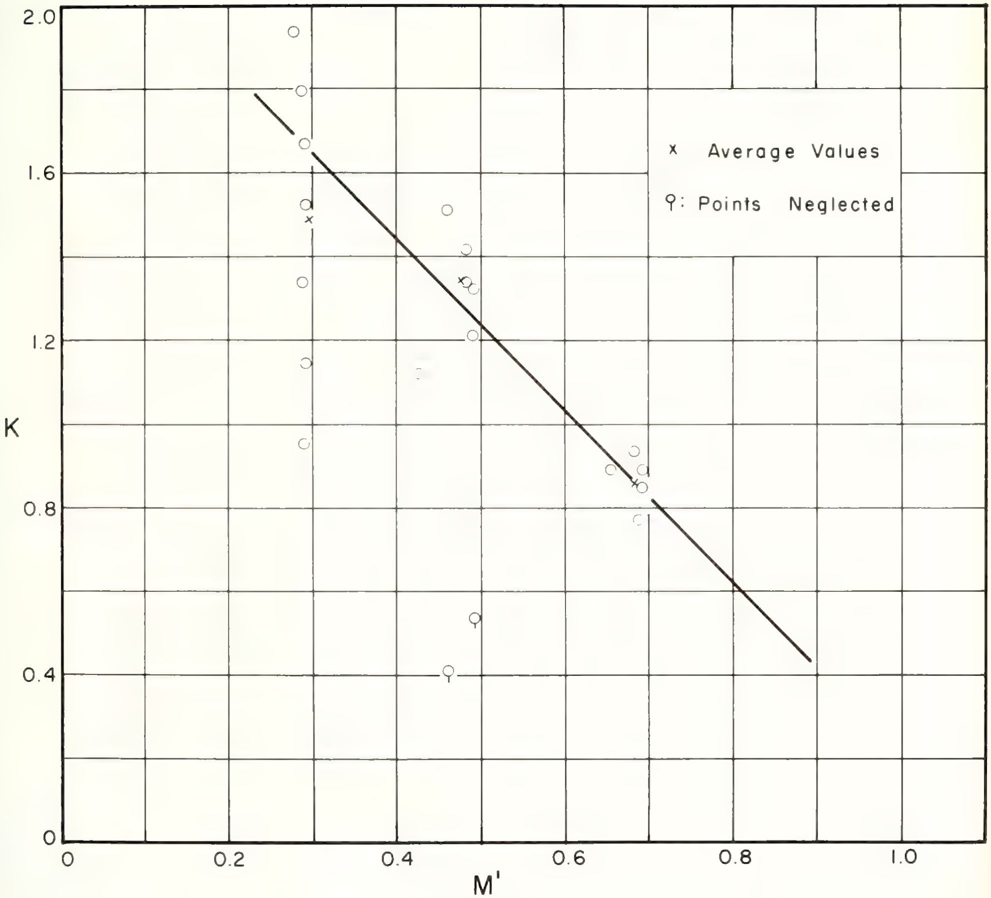


FIGURE 7-5-19 HEAD LOSS COEFFICIENT, GEOMETRY IV
ROUGH BOUNDARY e = 0.95

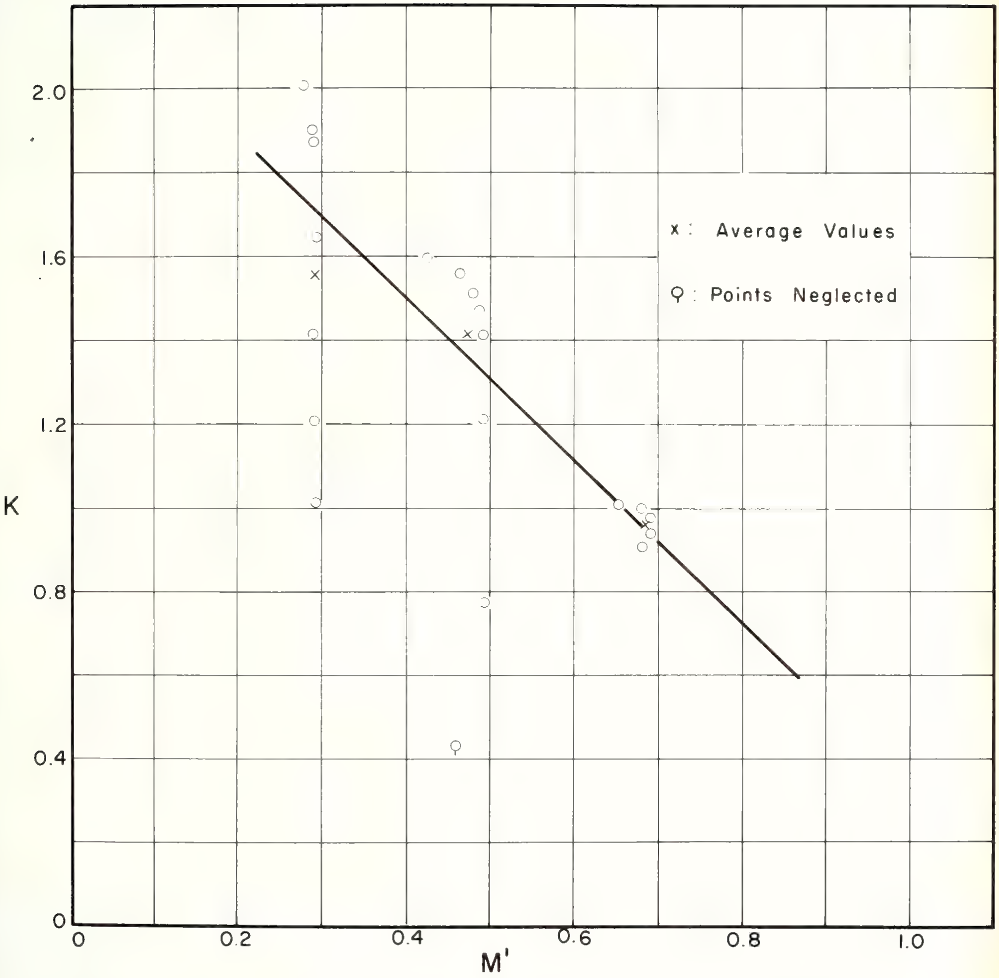


FIGURE 7-5-20 HEAD LOSS COEFFICIENT, GEOMETRY IV
ROUGH BOUNDARY e = 1.0

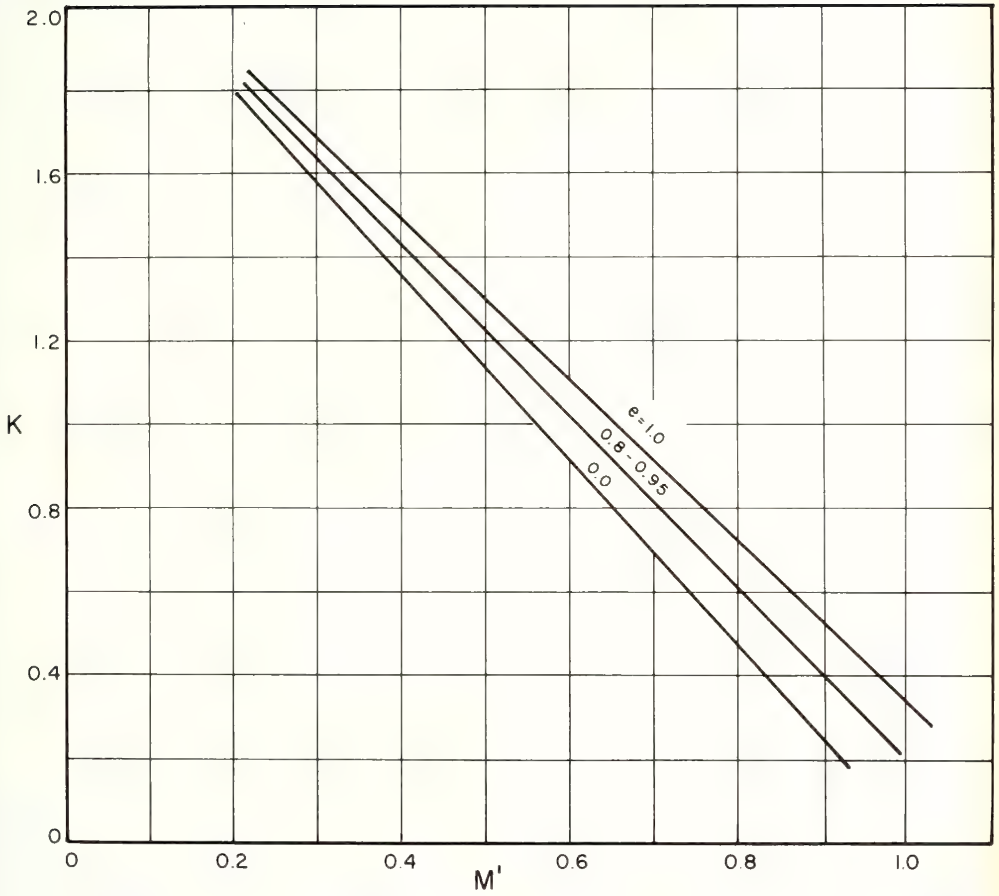


FIGURE 7-5-21 SUMMARY OF HEAD LOSS COEFFICIENTS
GEOMETRY IV ROUGH BOUNDARY

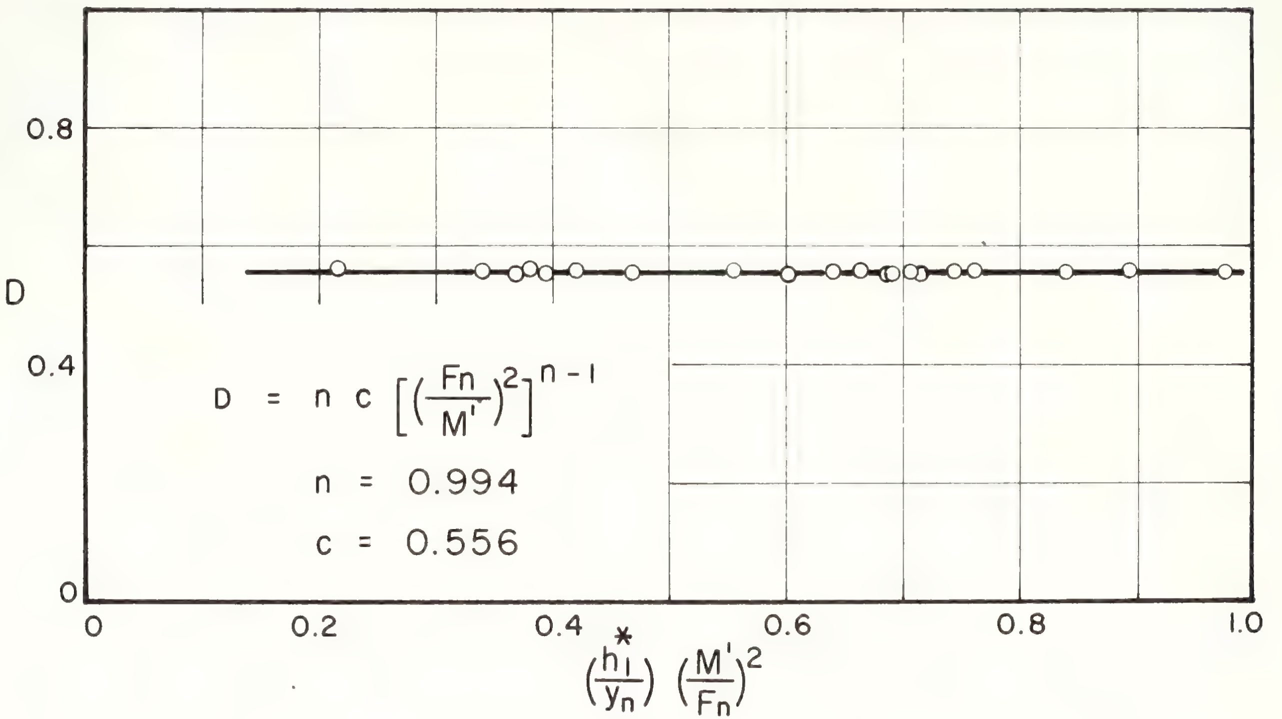


FIGURE 7-5-22 BACKWATER RATIO COEFFICIENT, GEOMETRY IV ROUGH BOUNDARY e = 0.0

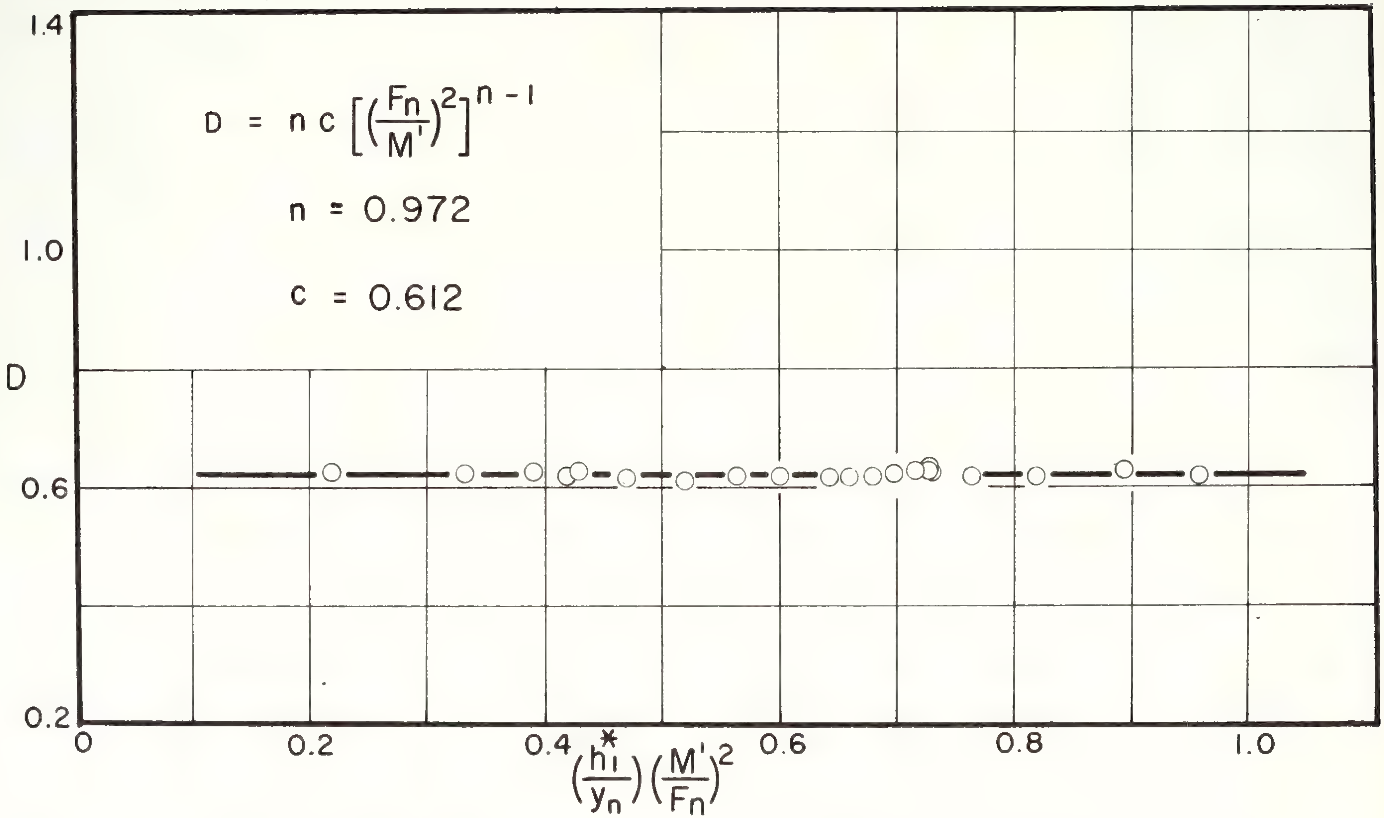


FIGURE 7-5-23 BACKWATER RATIO COEFFICIENT, GEOMETRY IV ROUGH BOUNDARY $e = 0.8$

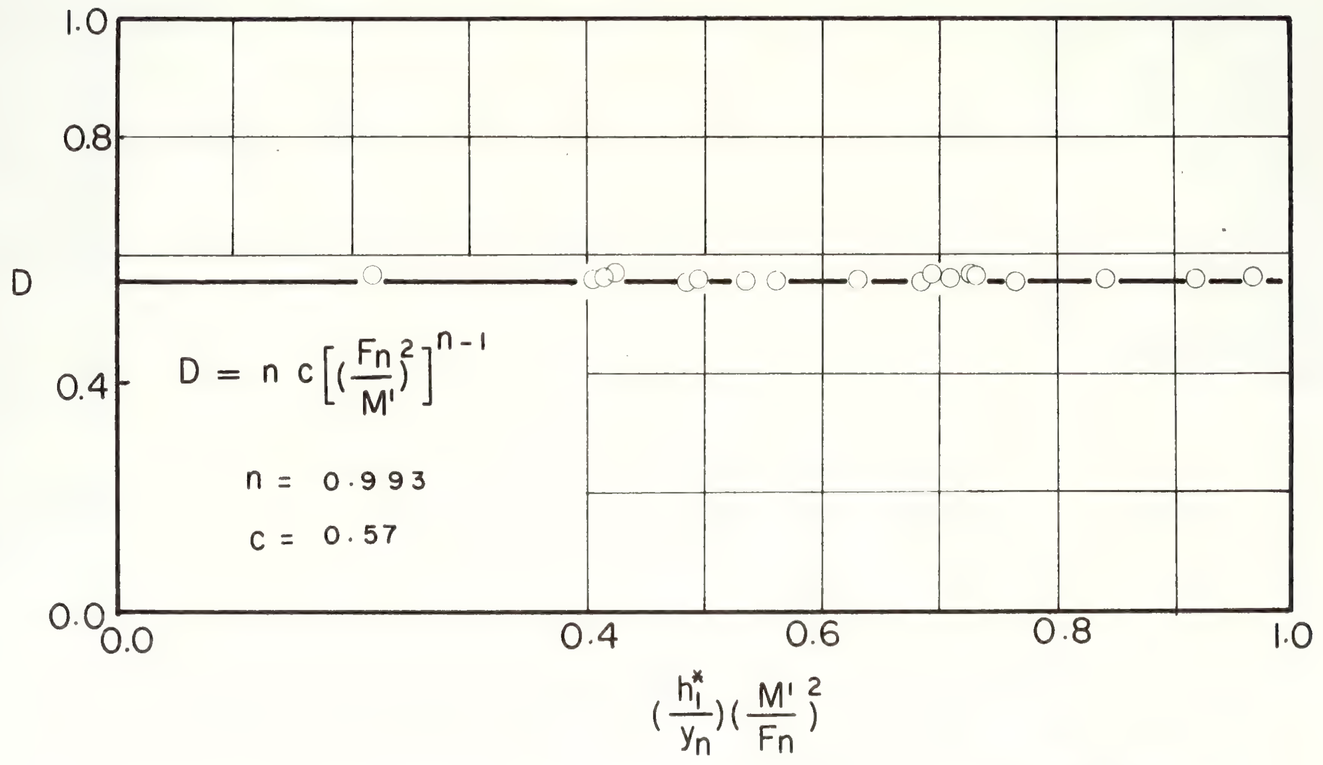


FIGURE 7-5-24 BACKWATER RATIO COEFFICIENT

GEOMETRY IV ROUGH BOUNDARY e = 0.85

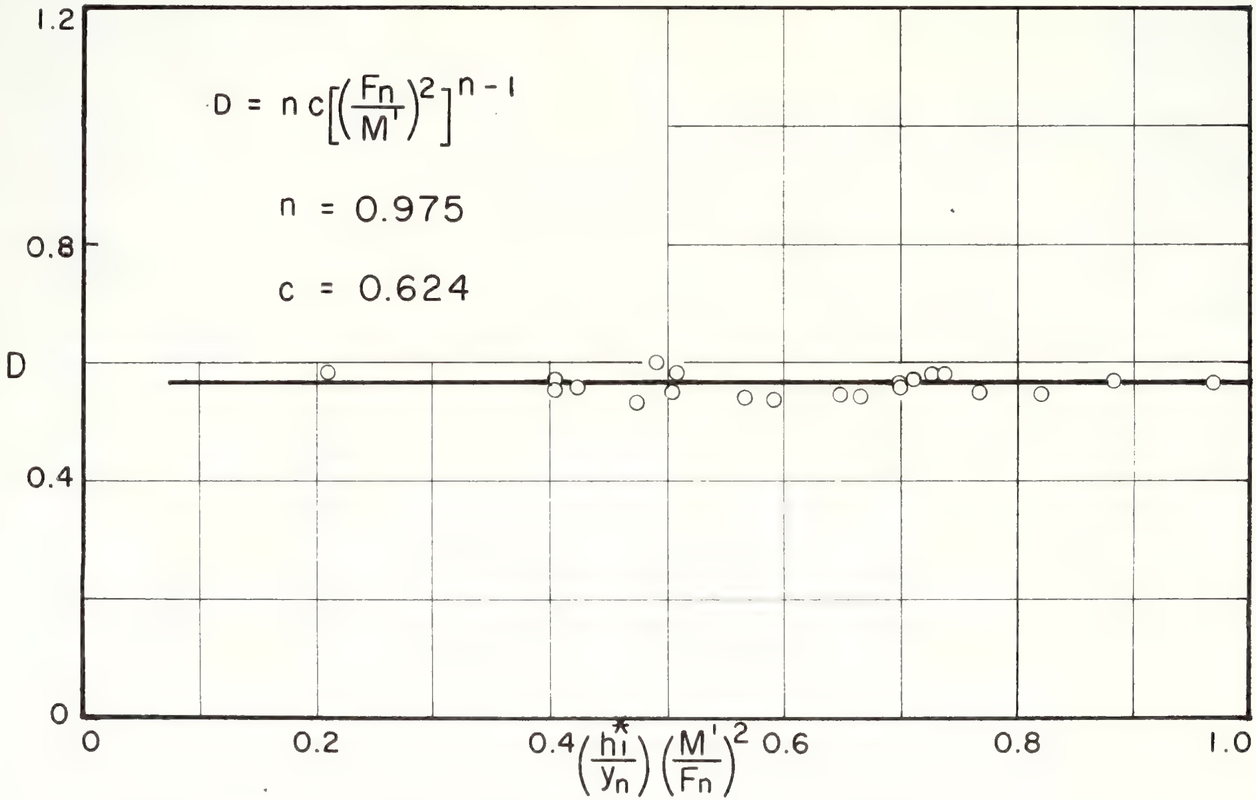


FIGURE 7-5-25 BACKWATER RATIO COEFFICIENT, GEOMETRY IV ROUGH BOUNDARY $e = 0.9$

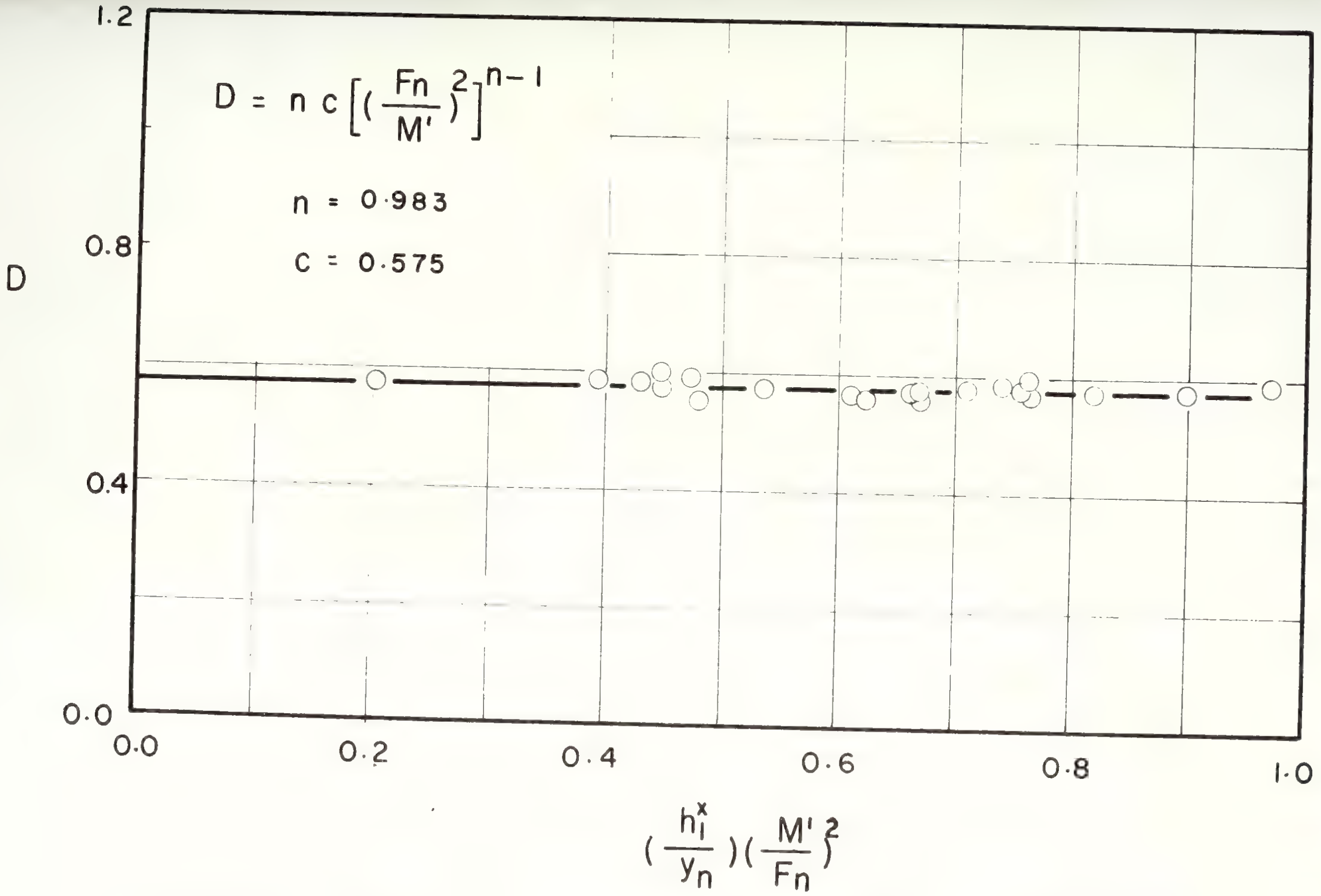


FIGURE 7-5-26 BACKWATER RATIO COEFFICIENT

GEOMETRY IV ROUGH BOUNDARY $e = 0.95$

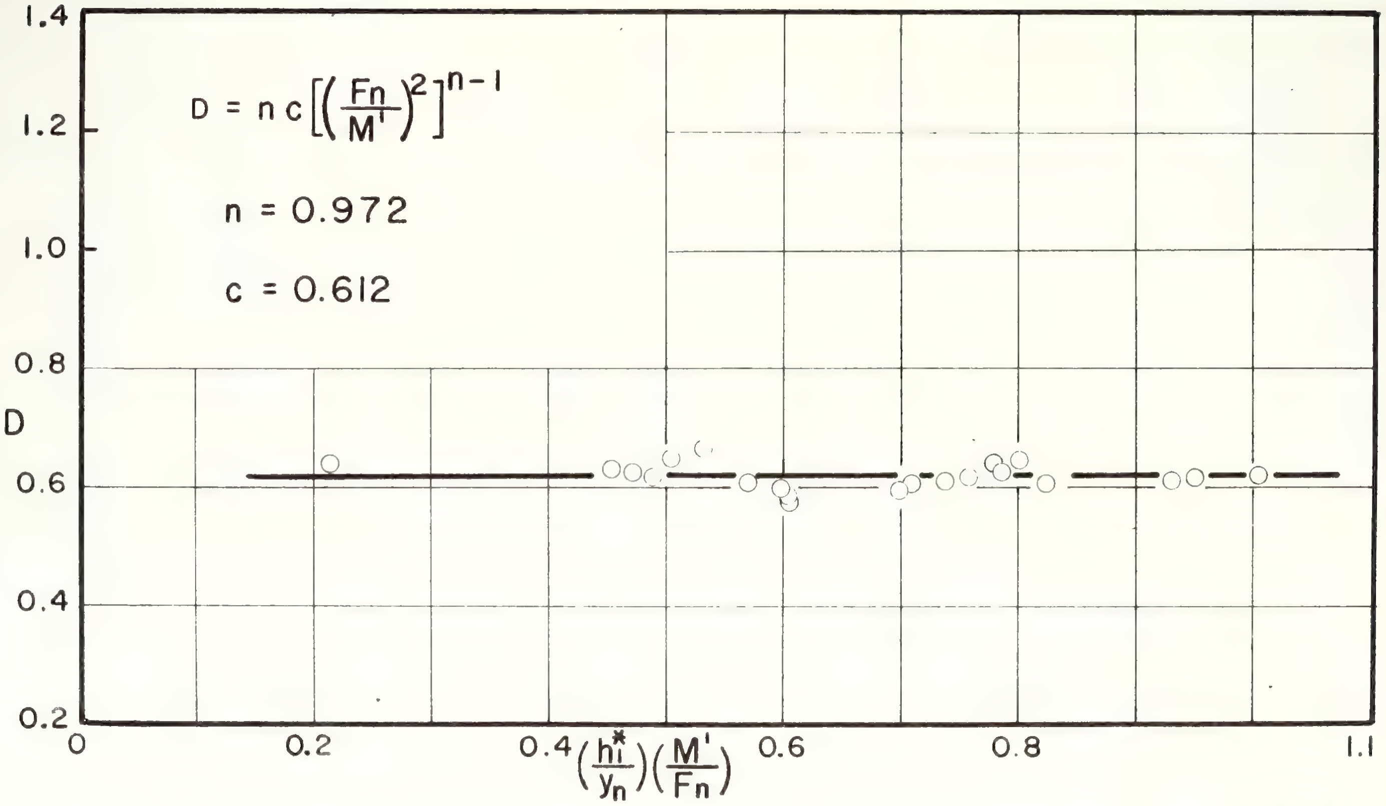


FIGURE 7-5-27 BACKWATER RATIO COEFFICIENT GEOMETRY IV ROUGH BOUNDARY $e = 1.0$

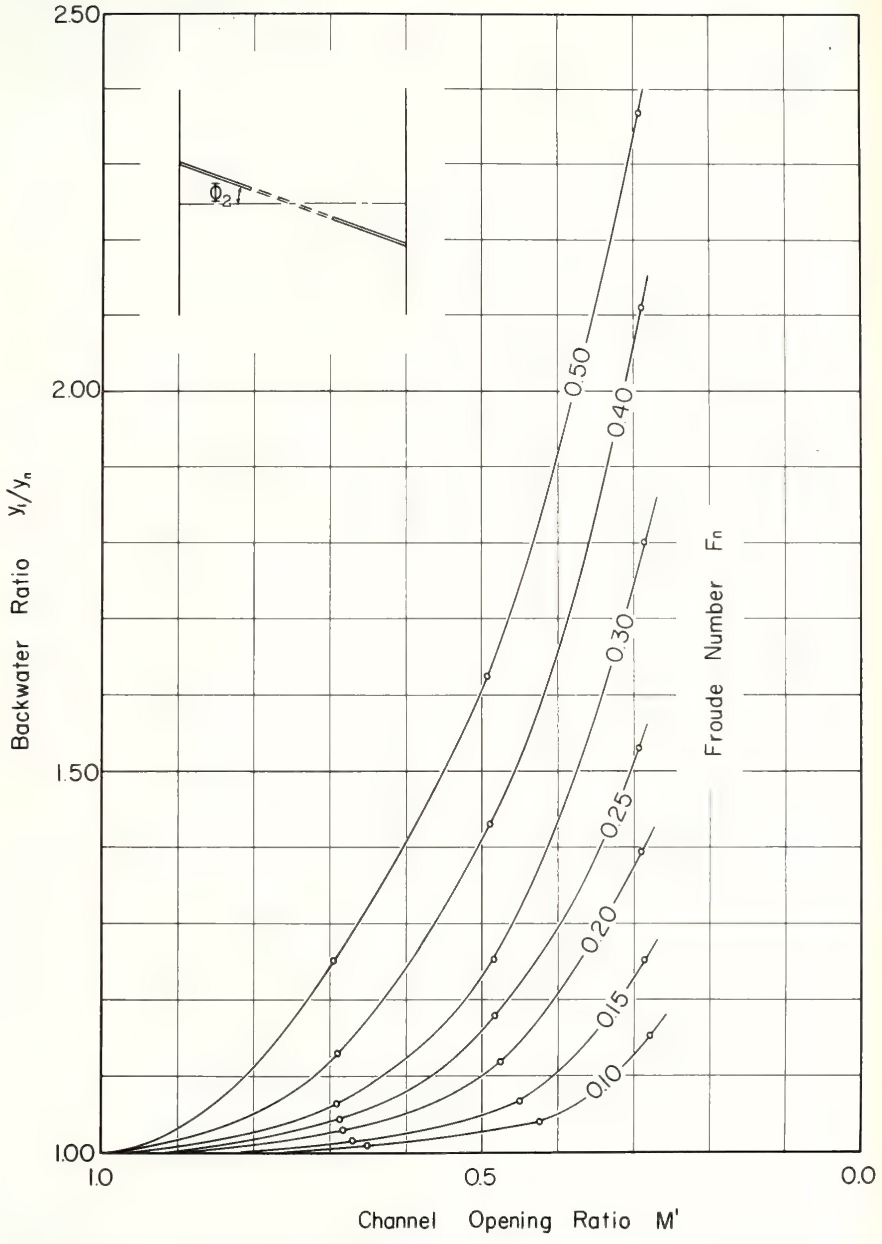


FIG. 7-6-1 -BACKWATER RATIO FOR SKEW ARCH BRIDGES
$\Phi_2 = 0°$

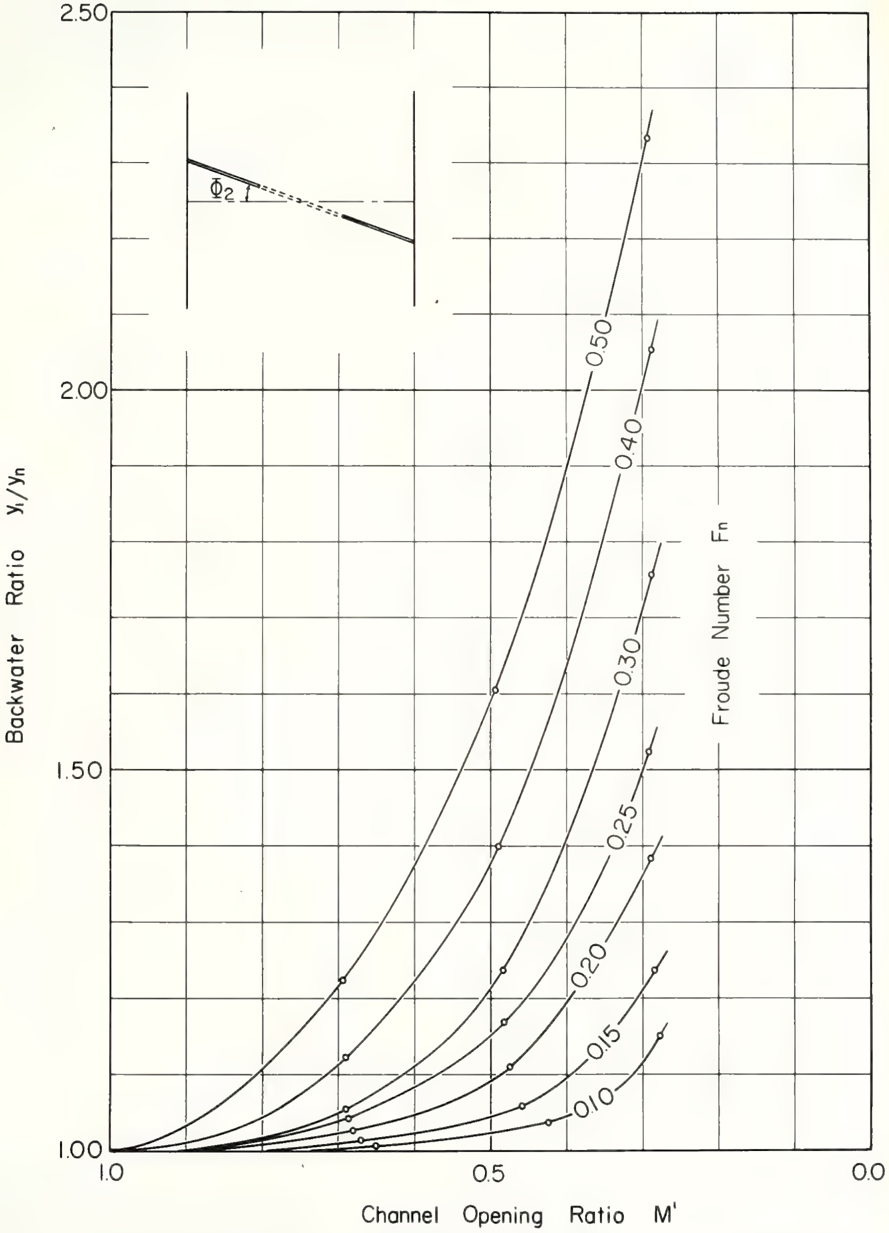


FIG. 7-6-2 -BACKWATER RATIO FOR SKEW ARCH BRIDGES

$\Phi_2 = 15°$

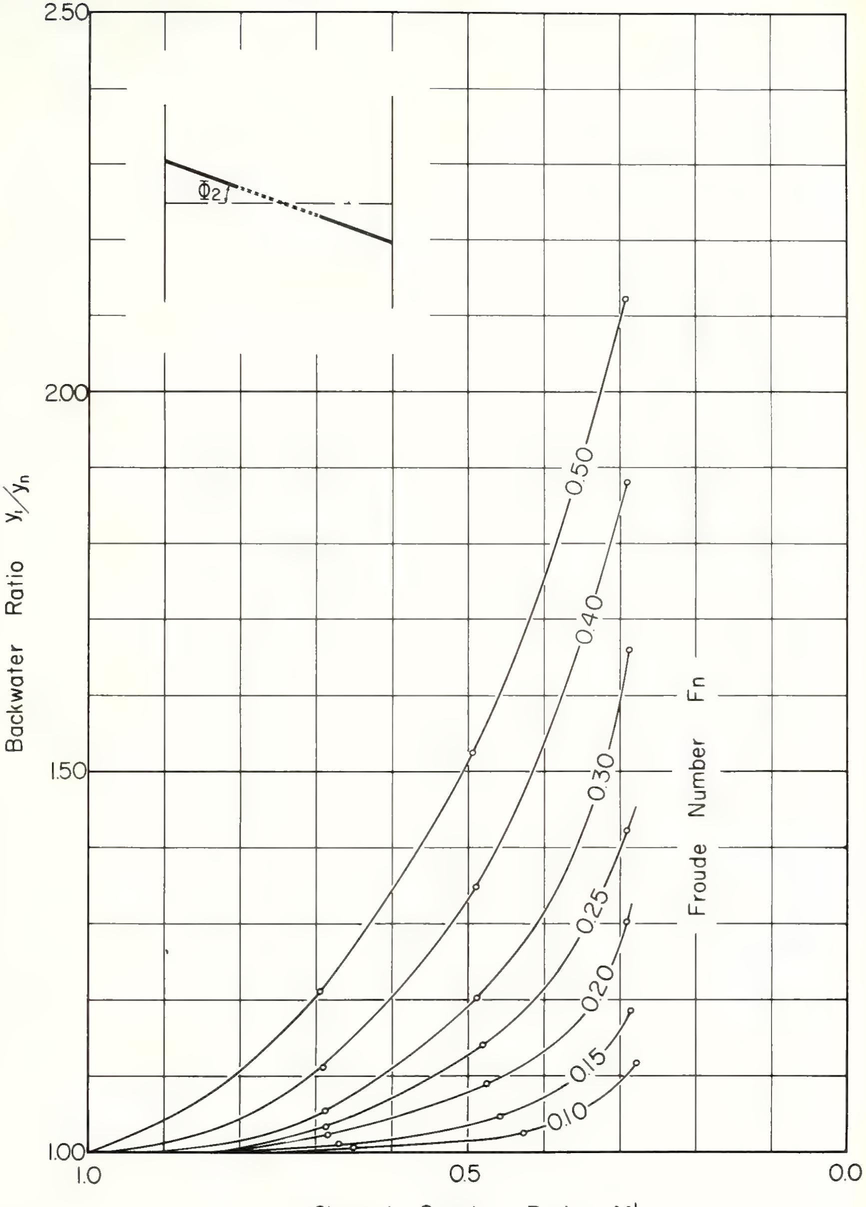


FIG. 7-6-3 -BACKWATER RATIO FOR SKEW ARCH BRIDGES

$\Phi_2 = 30°$

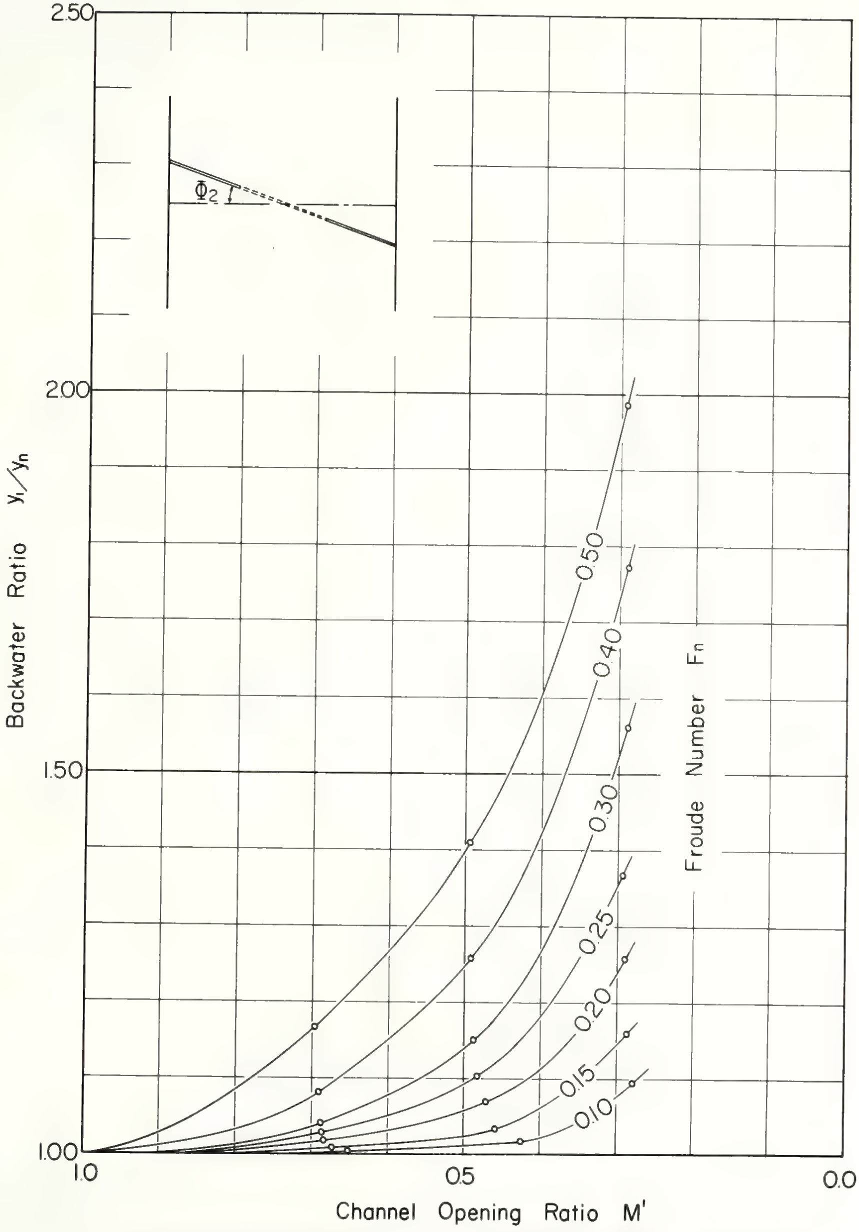


FIG. 7-6-4-BACKWATER RATIO FOR SKEW ARCH BRIDGES

$\Phi_2 = 45°$

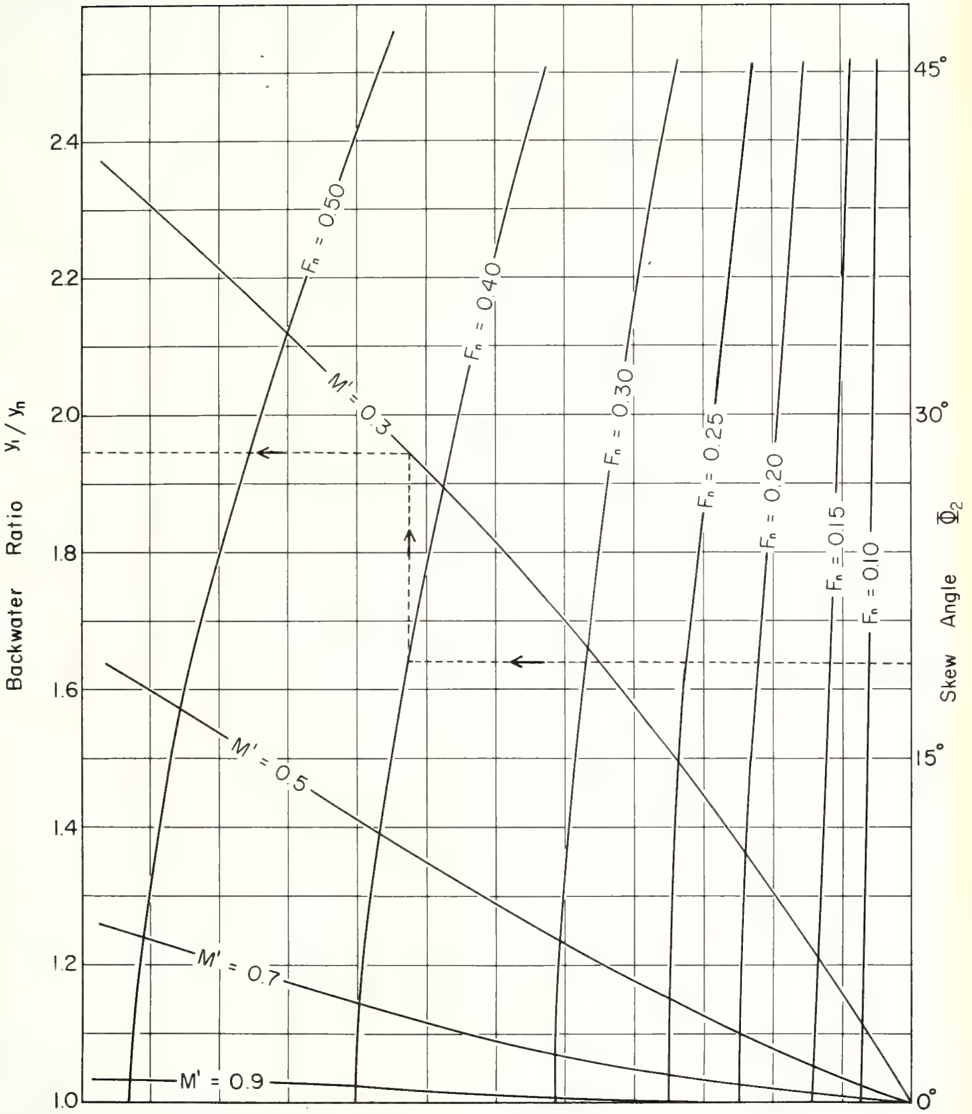
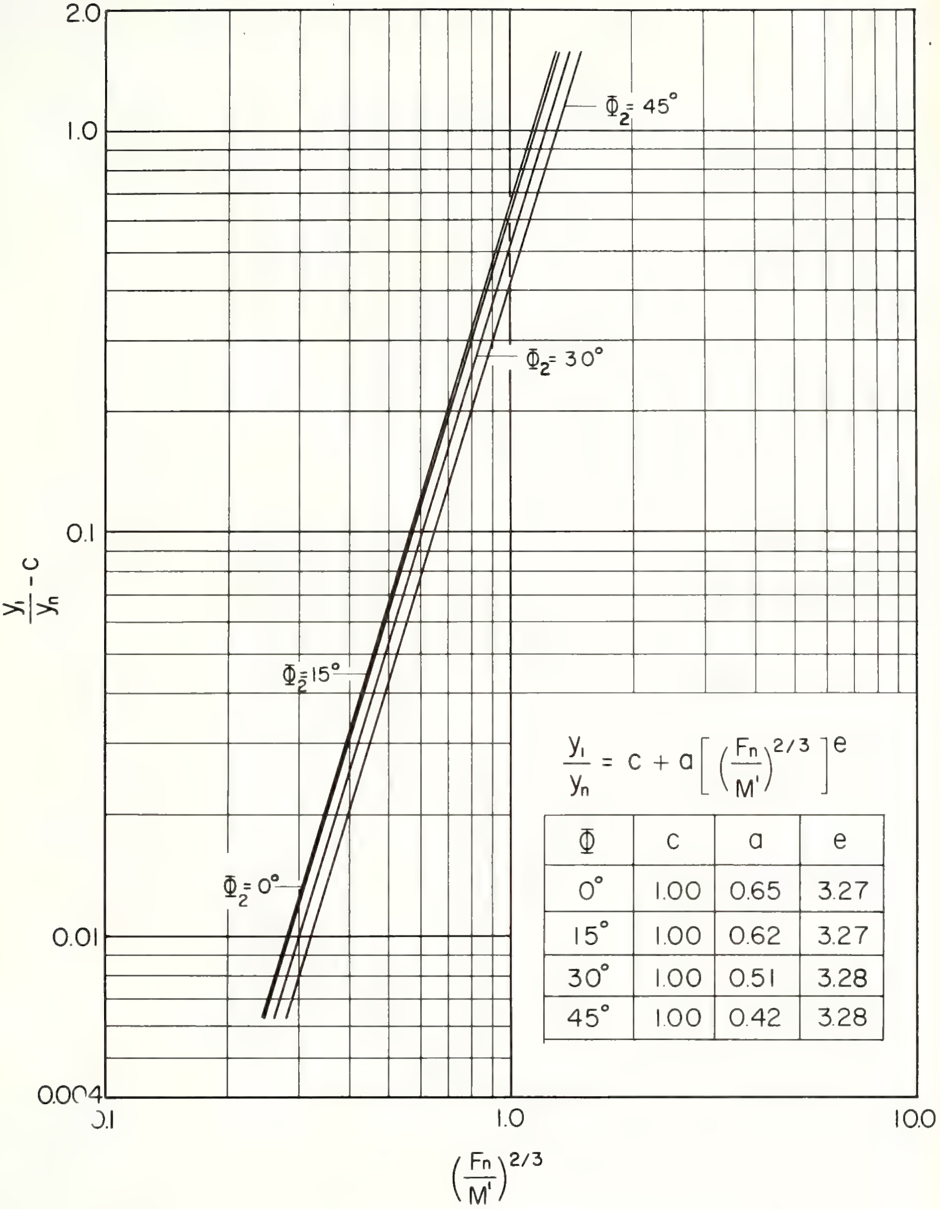


FIG. 7-6-5 - BACKWATER RATIO FOR SKEW ARCH BRIDGE



$$\frac{y_1}{y_n} = c + a\left[\left(\frac{F_n}{M'}\right)^{2/3}\right]^e$$

Φ	c	a	e
0°	1.00	0.65	3.27
15°	1.00	0.62	3.27
30°	1.00	0.51	3.28
45°	1.00	0.42	3.28

FIG. 7-6-6 - GENERALIZED BACKWATER RATIO FOR SKEW ARCH BRIDGE

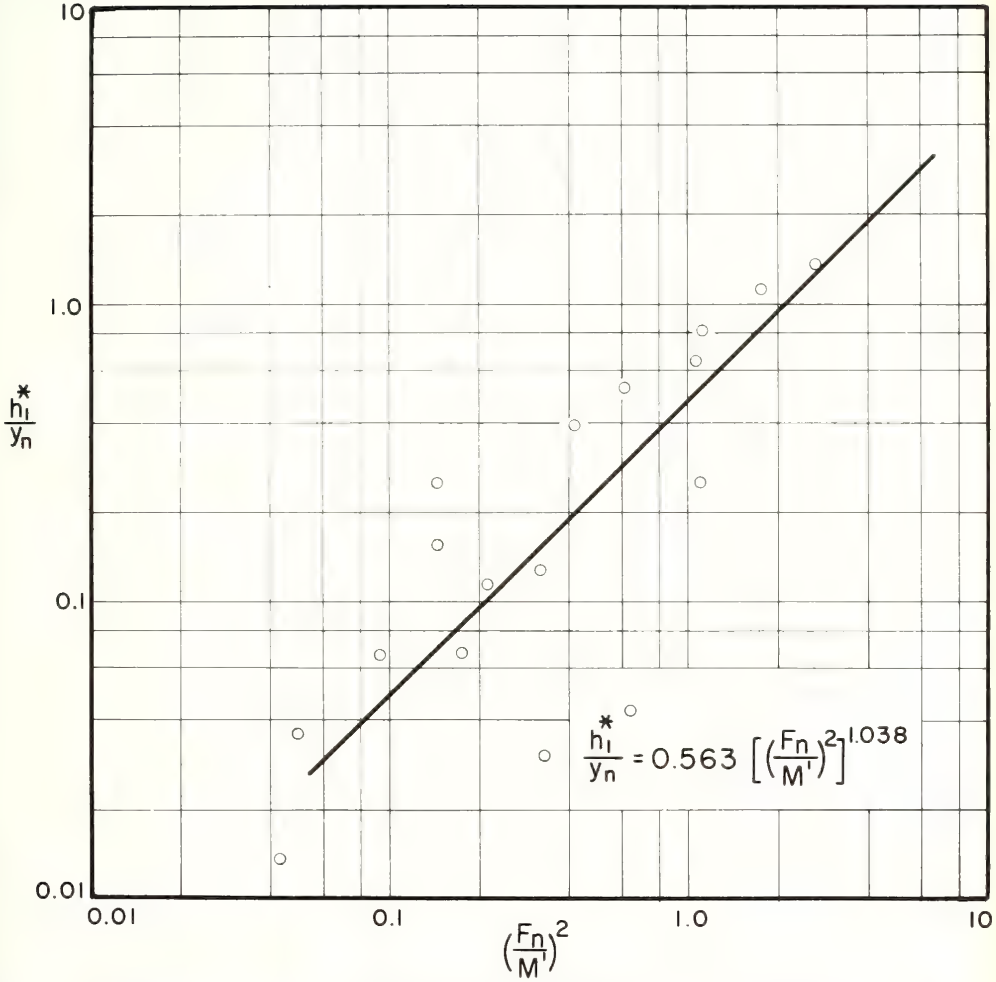


FIGURE 7-6-7 BACKWATER RATIO, GEOMETRY Va

ROUGH BOUNDARY Φ_2 = 0.00

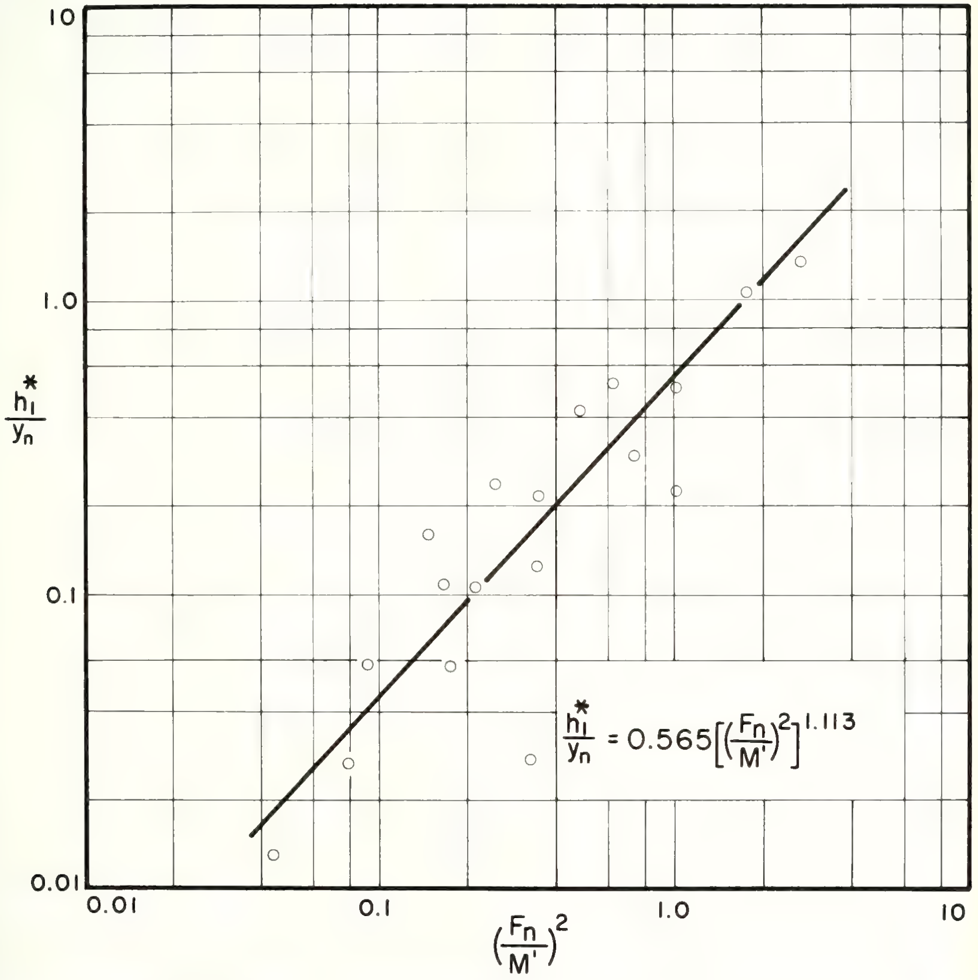


FIGURE 7-6-8 BACKWATER RATIO, GEOMETRY V_a
ROUGH BOUNDARY $\Phi_2 = 15°$

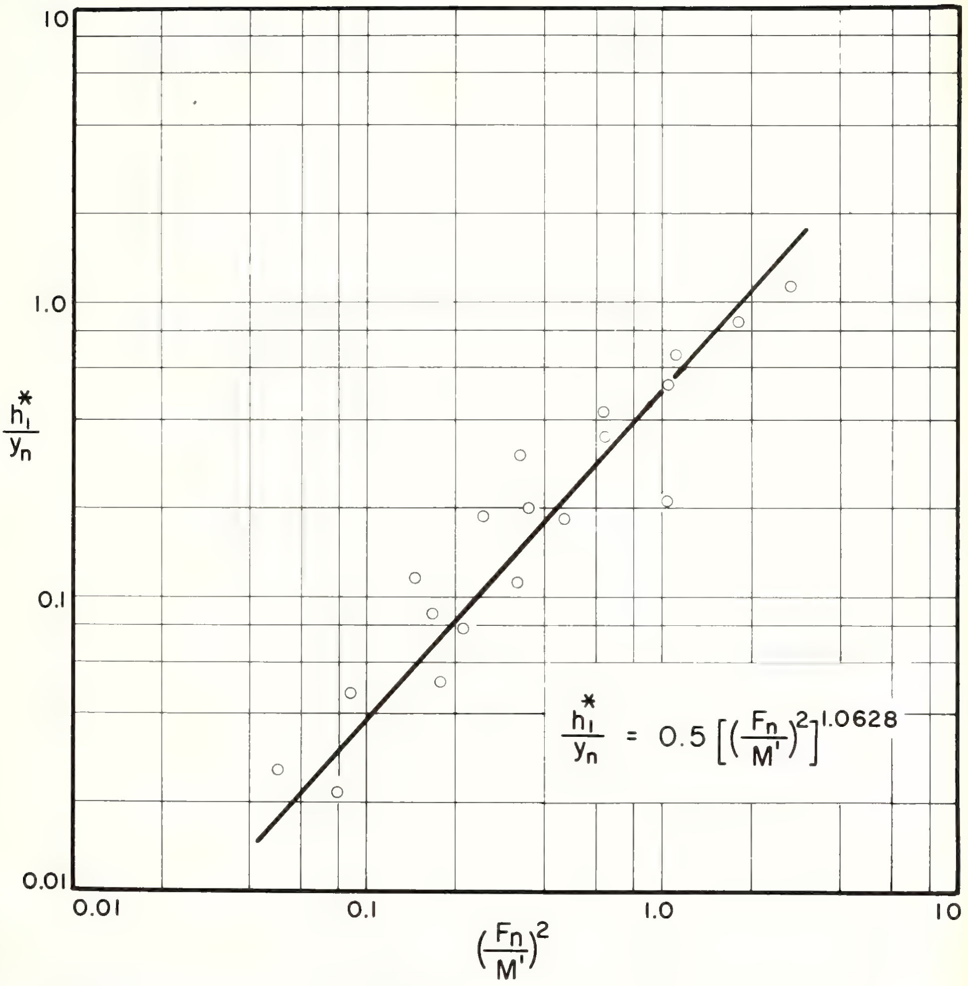


FIGURE 7-6-9 BACKWATER RATIO, GEOMETRY V_a

ROUGH BOUNDARY $\Phi_2 = 30°$

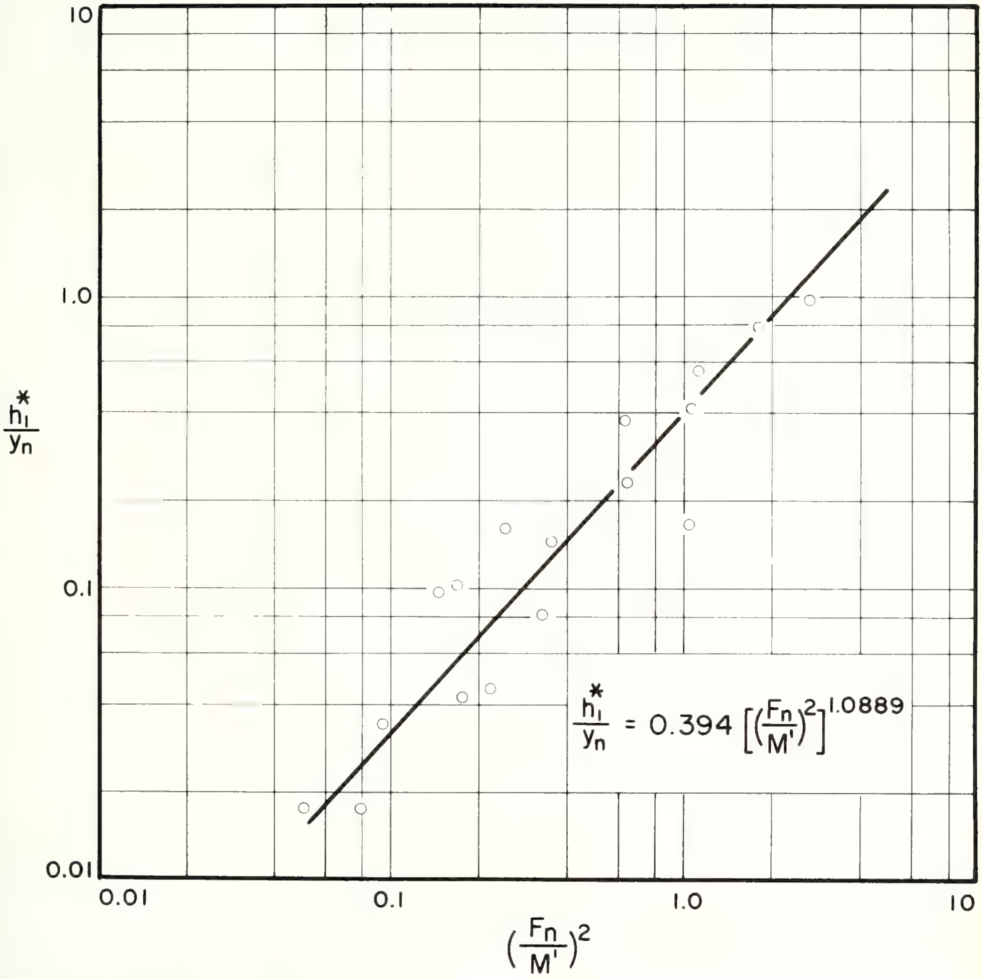


FIGURE 7-6-10 BACKWATER RATIO, GEOMETRY V_a

ROUGH BOUNDARY $\Phi_2 = 45°$

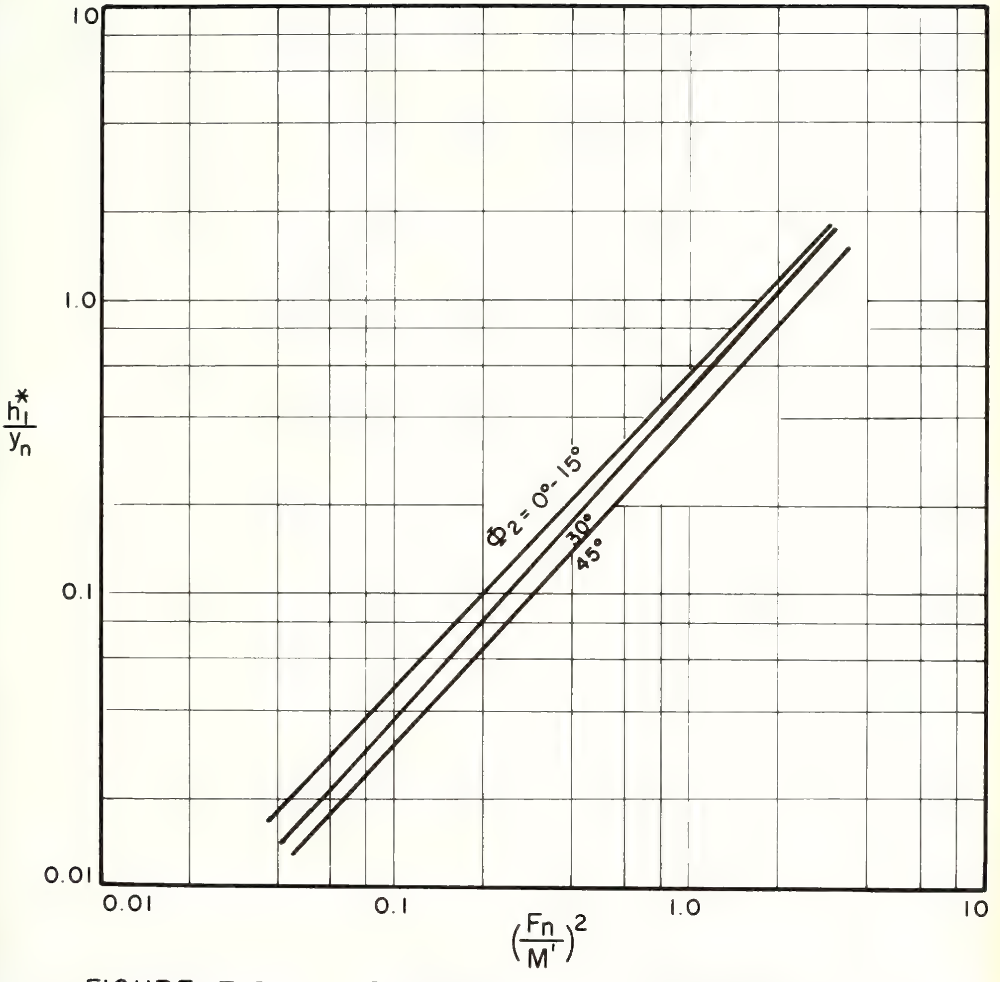


FIGURE 7-6-11 SUMMARY OF BACKWATER RATIO GEOMETRY V_a ROUGH BOUNDARY

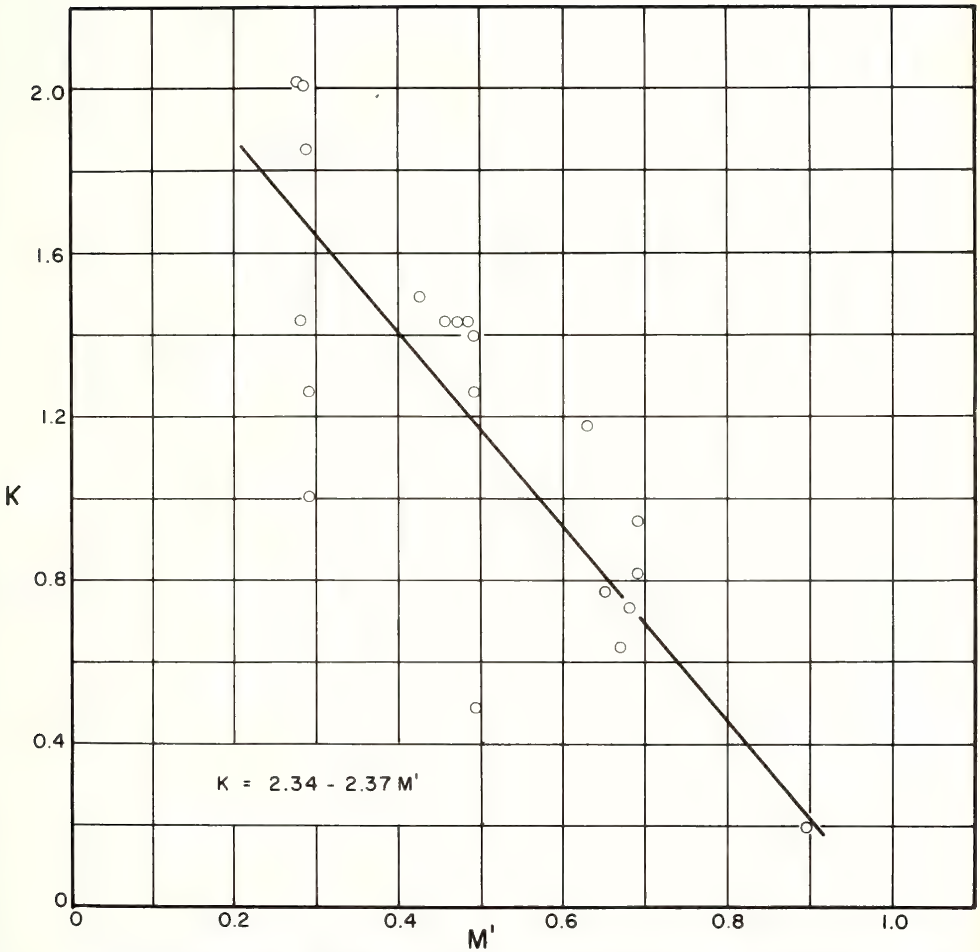


FIGURE 7-6-12 HEAD LOSS COEFFICIENT, GEOMETRY V_a
ROUGH BOUNDARY $\Phi_2 = 0.0°$

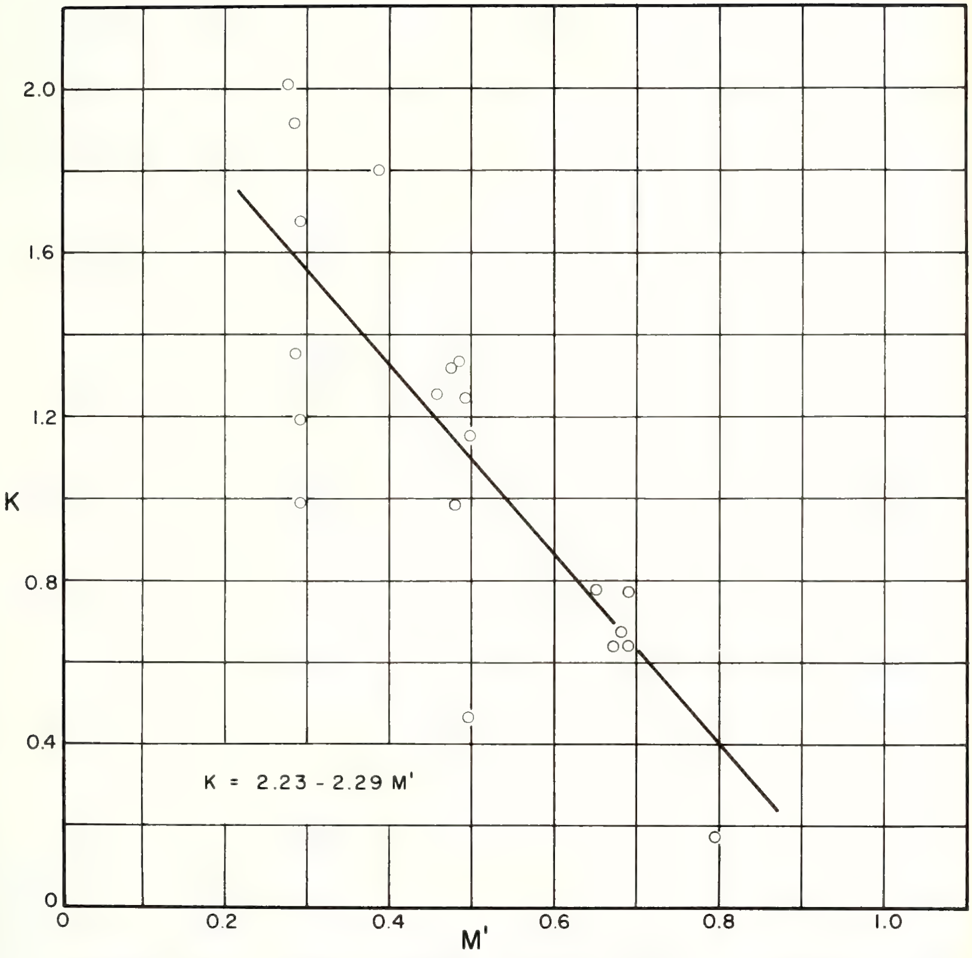


FIGURE 7-6-13 HEAD LOSS COEFFICIENT, GEOMETRY V_a
ROUGH BOUNDARY $\Phi_2 = 15°$

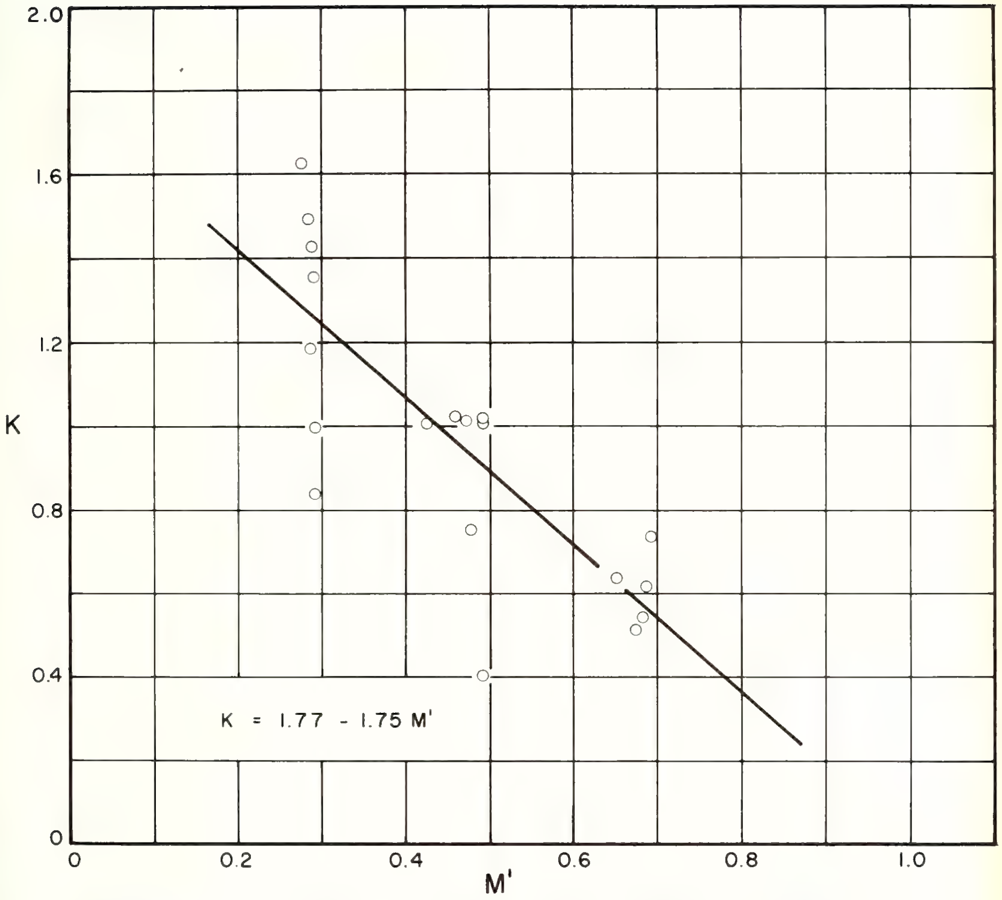


FIGURE 7-6-14 HEAD LOSS COEFFICIENT, GEOMETRY V_a
ROUGH BOUNDARY $\Phi_2 = 30°$

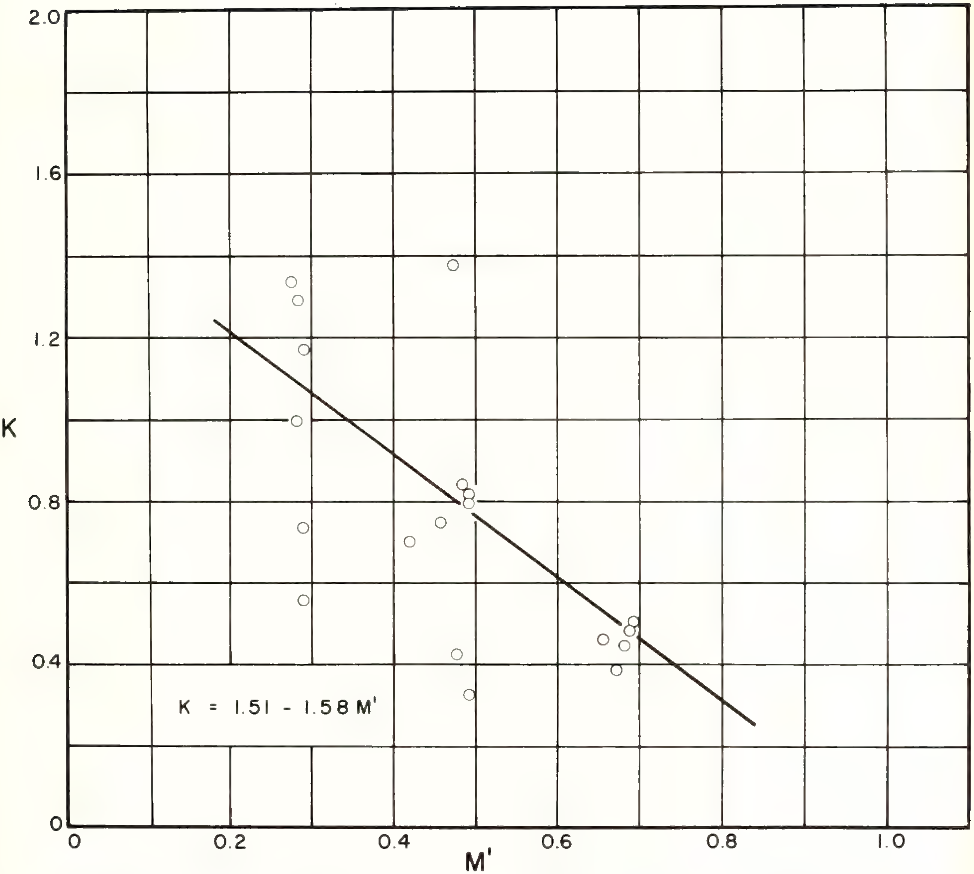


FIGURE 7-6-15 HEAD LOSS COEFFICIENT, GEOMETRY Va
ROUGH BOUNDARY $\Phi_2 = 45°$

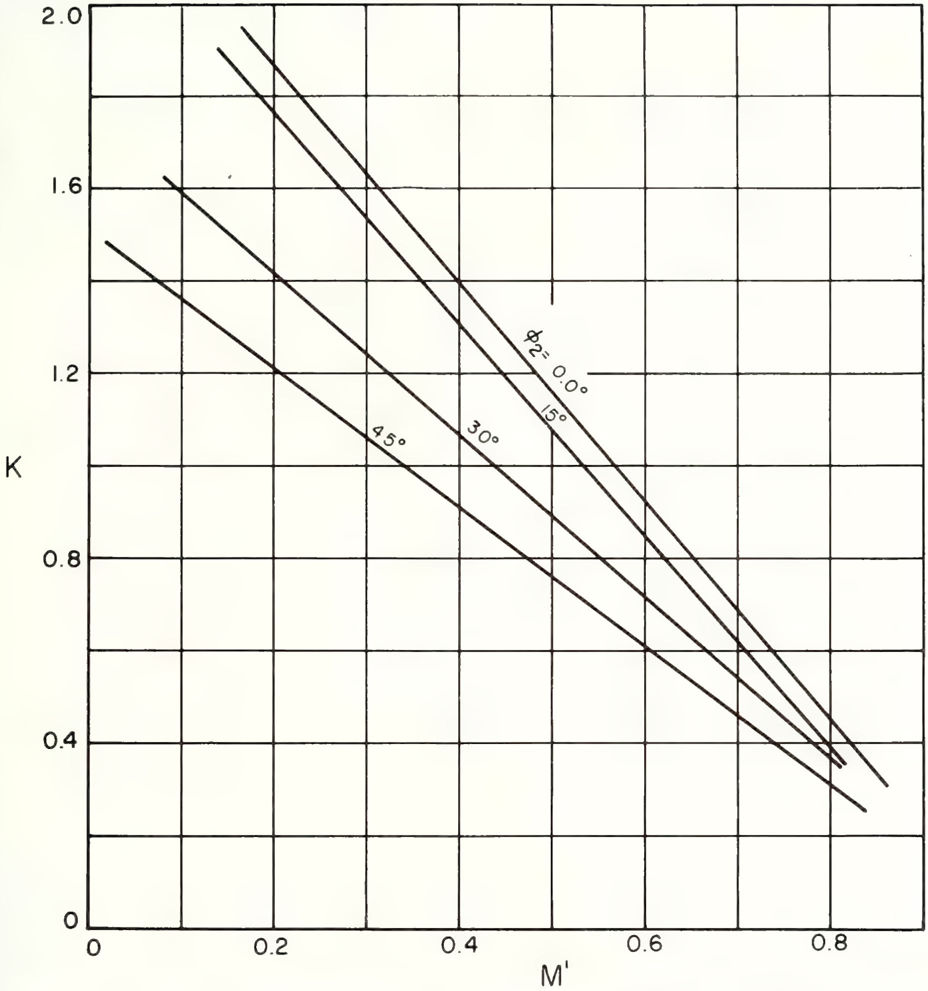


FIGURE 7-6-16 SUMMARY OF HEAD LOSS COEFFICIENTS GEOMETRY $\mathrm{V_a}$. ROUGH BOUNDARIES

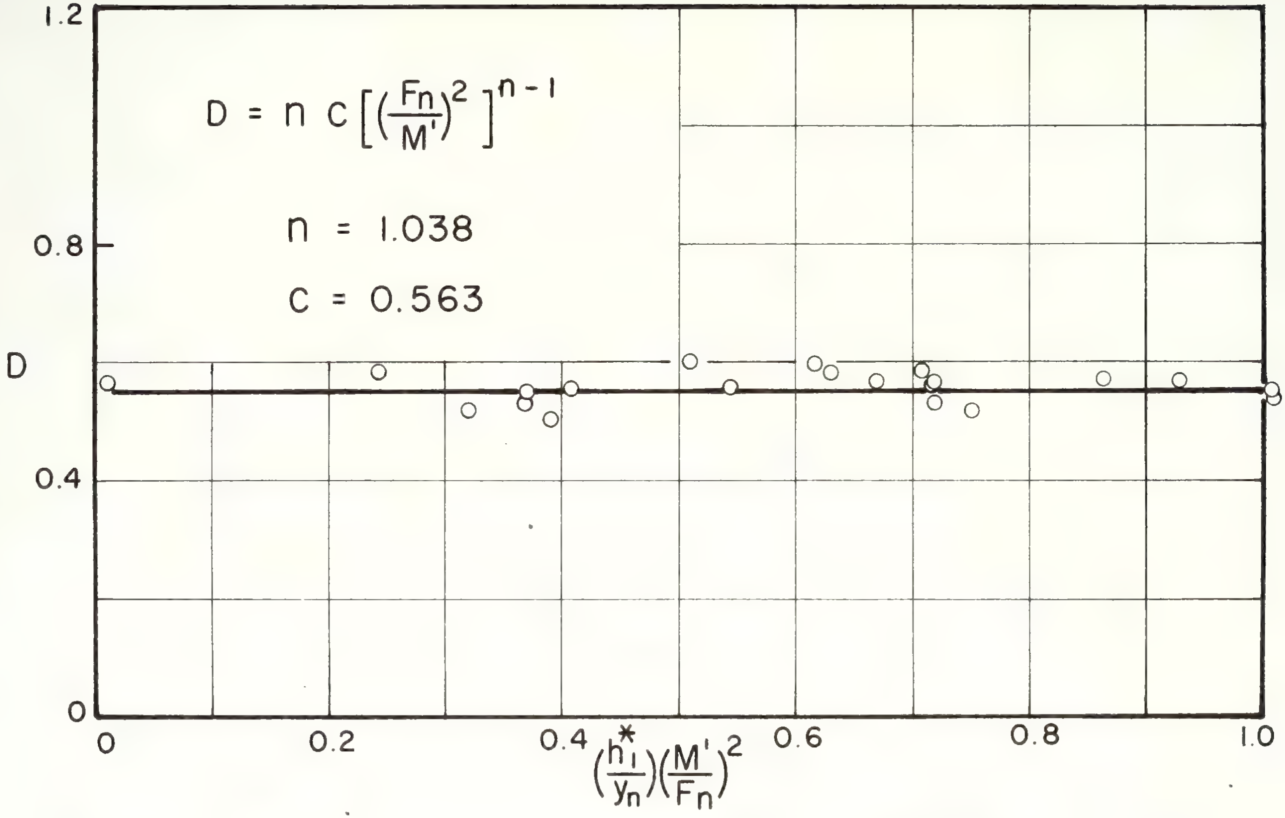


FIGURE 7-6-17 BACKWATER RATIO COEFFICIENT, GEOMETRY V_a ROUGH BOUNDARY $\Phi_2 = 0.0$

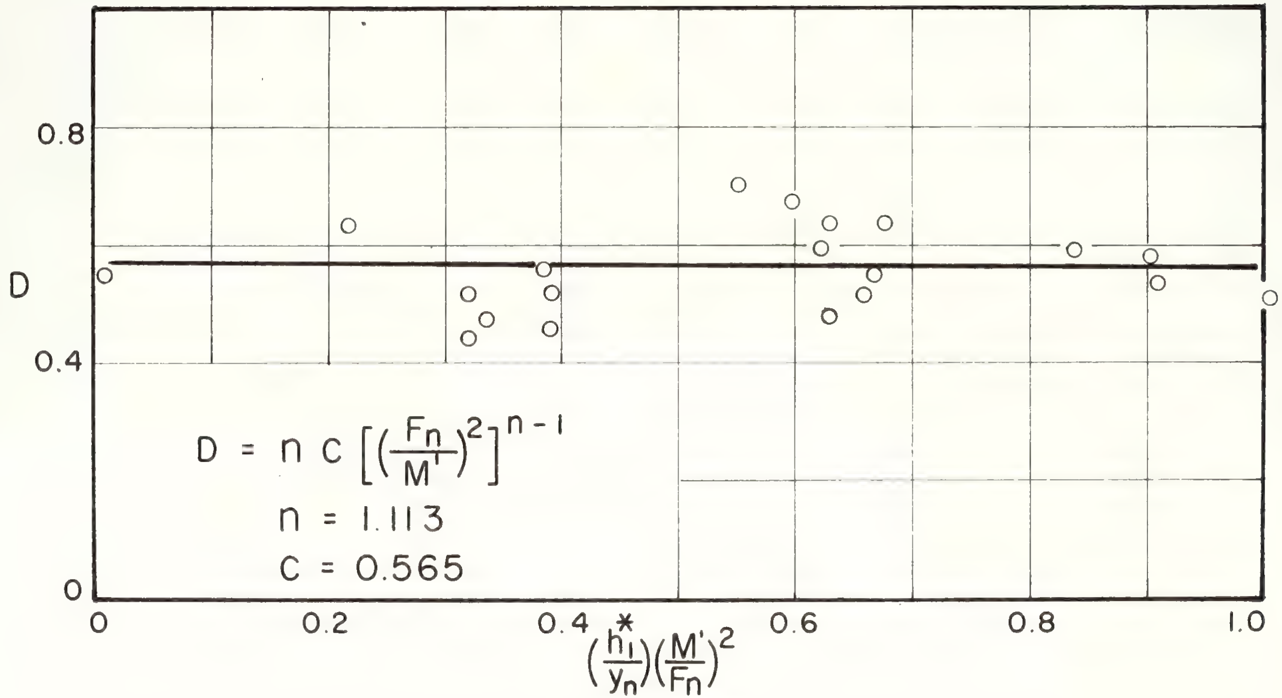


FIGURE 7-6-18 BACKWATER RATIO COEFFICIENT, GEOMETRY V_a ROUGH BOUNDARY $\Phi_2 = 15°$

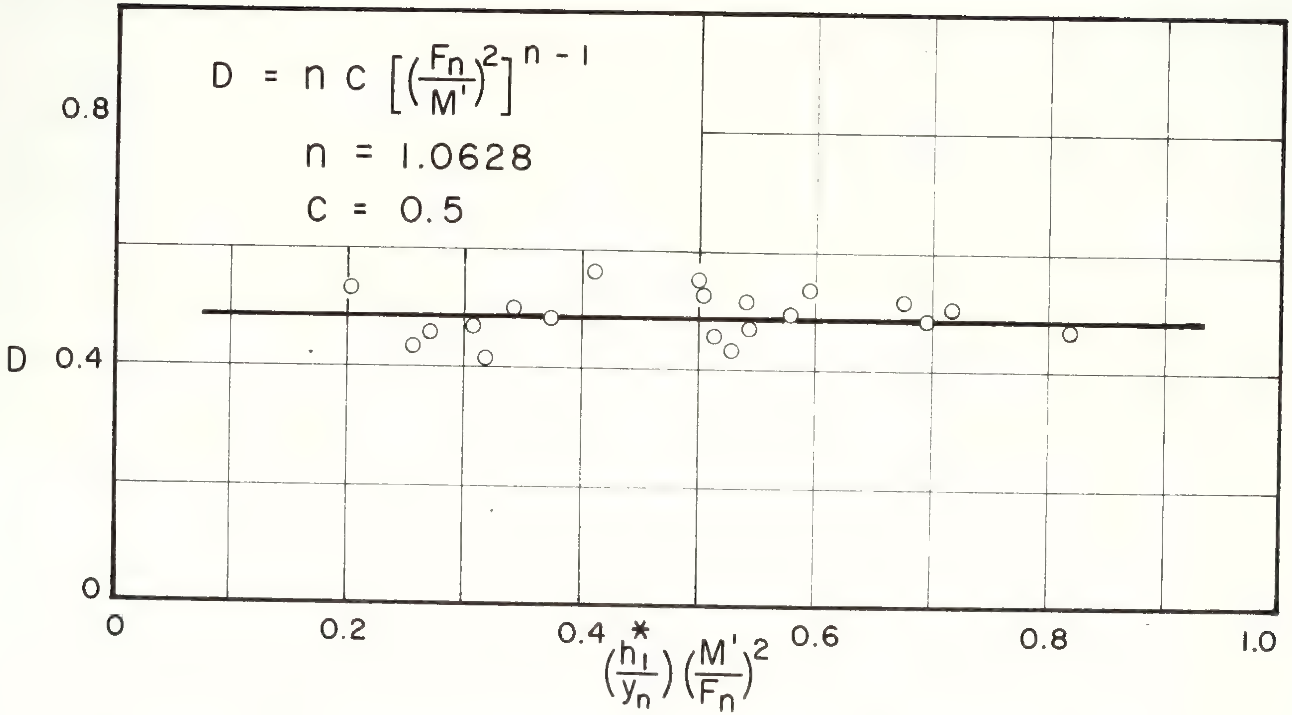


FIGURE 7-6-19 BACKWATER RATIO COEFFICIENT, GEOMETRY V_a ROUGH BOUNDARY $\Phi_2 = 30°$

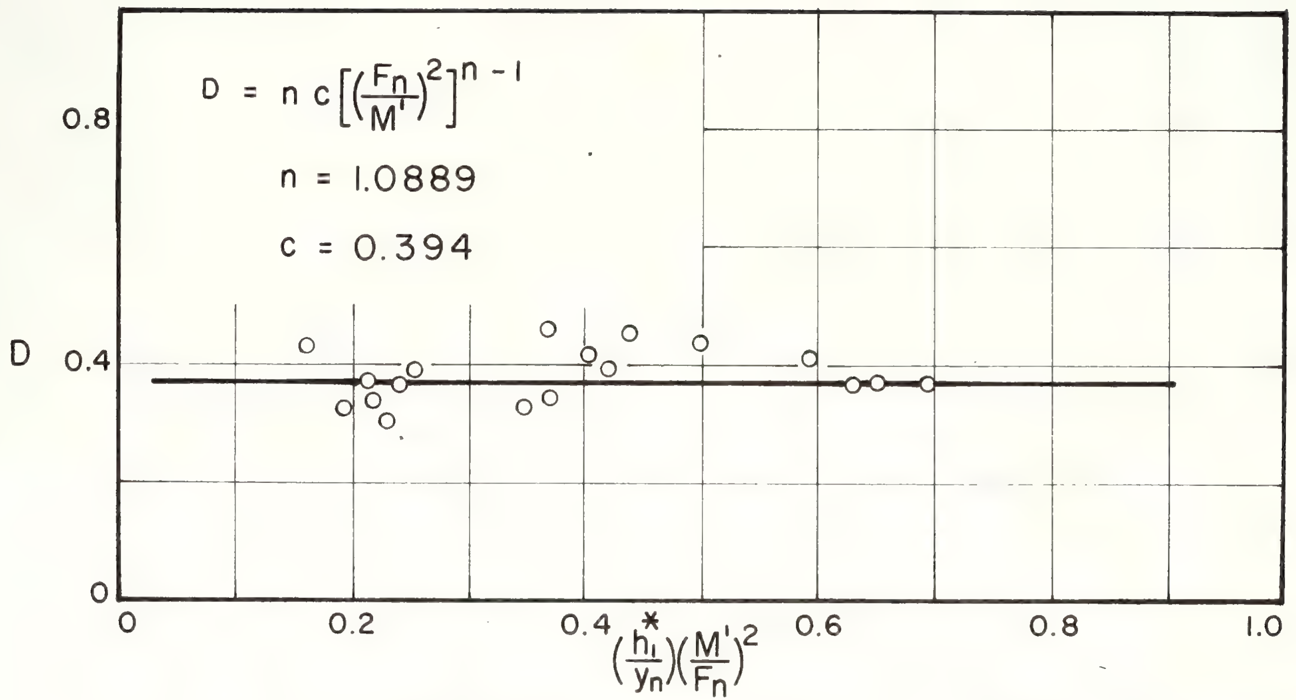


FIGURE 7-6-20 BACKWATER RATIO COEFFICIENT, GEOMETRY V_a ROUGH BOUNDARY $\Phi_2 = 45°$

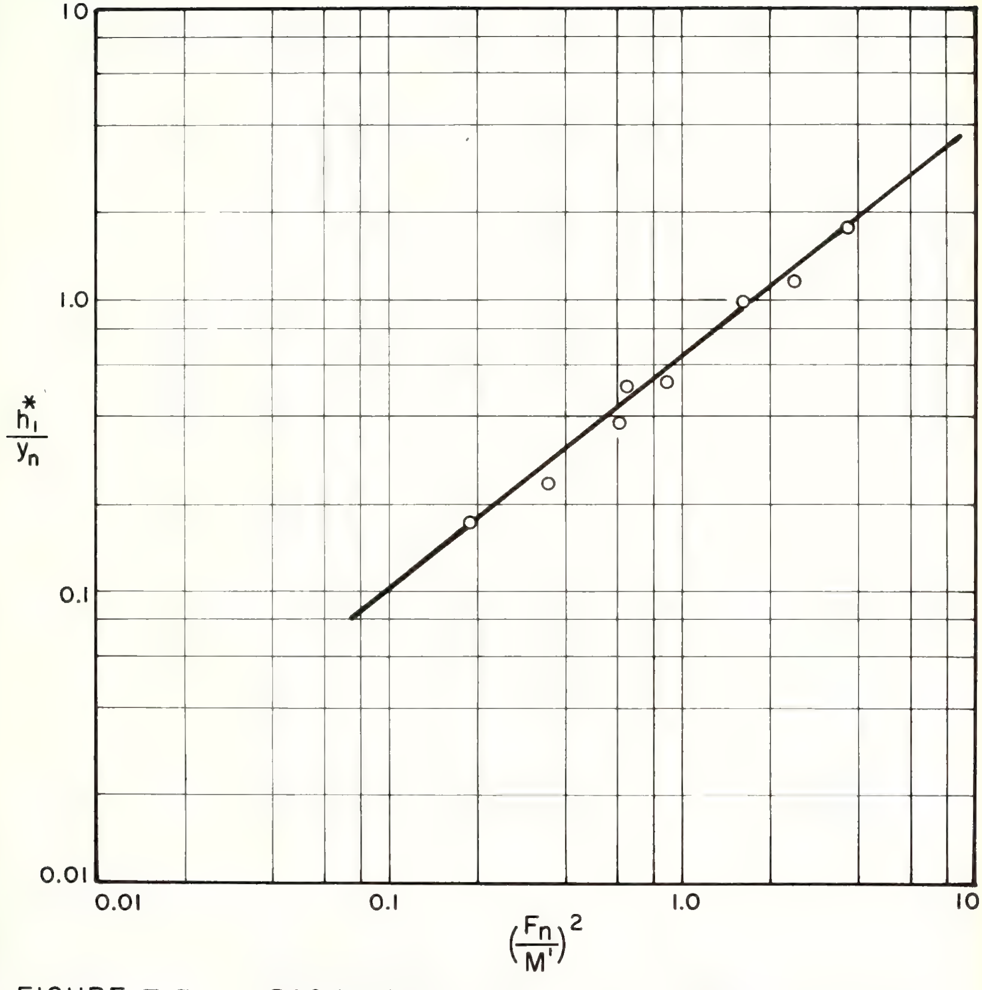


FIGURE 7-7-1 BACKWATER RATIO, GEOMETRY V_b

ROUGH BOUNDARY $\Phi_2 = 15°$

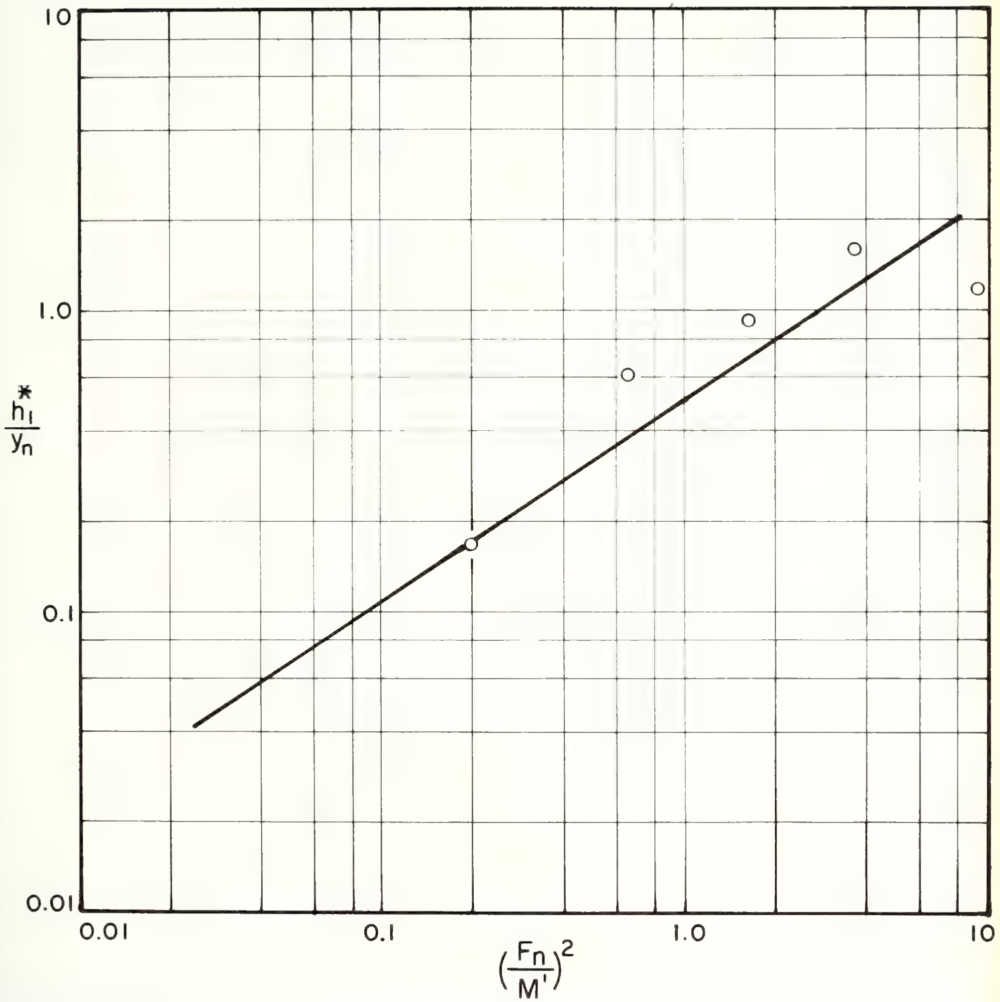


FIGURE 7-7-2 BACKWATER RATIO, GEOMETRY V_b

ROUGH BOUNDARY $\Phi_2 = 30°$

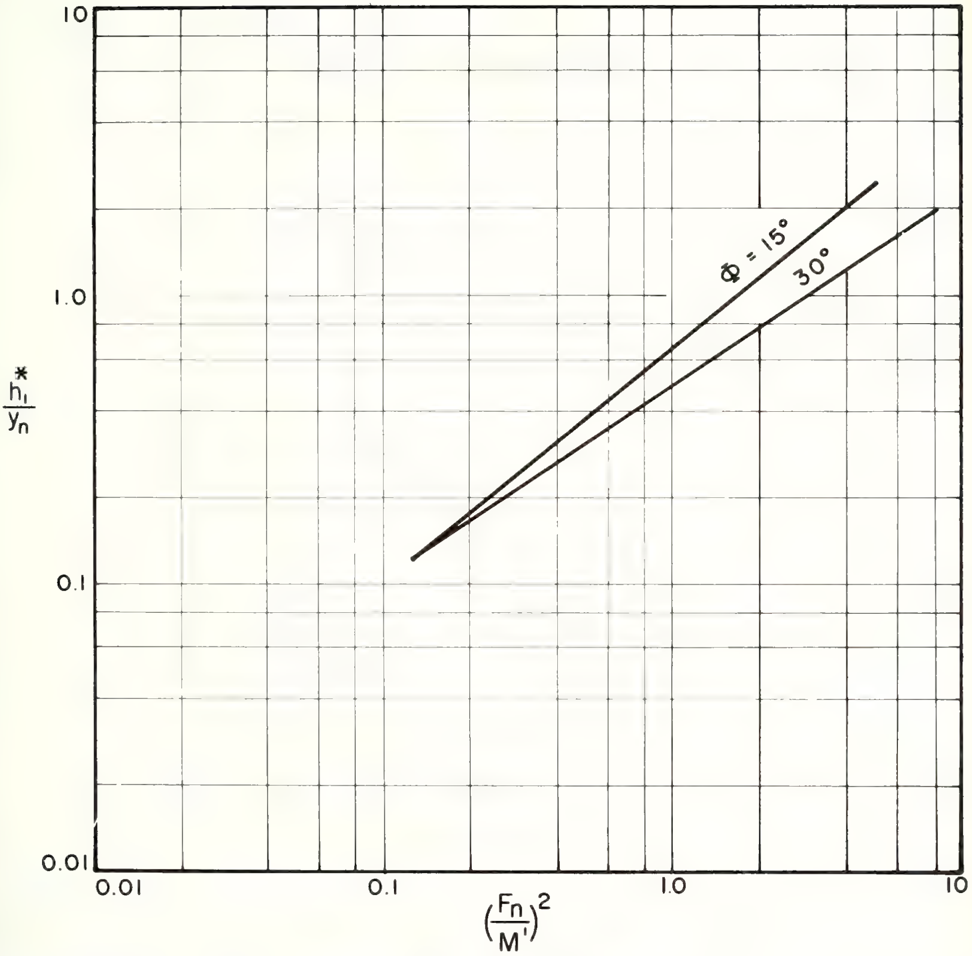


FIGURE 7-7-3 SUMMARY OF BACKWATER RATIO, GEOMETRY V_b ROUGH BOUNDARY

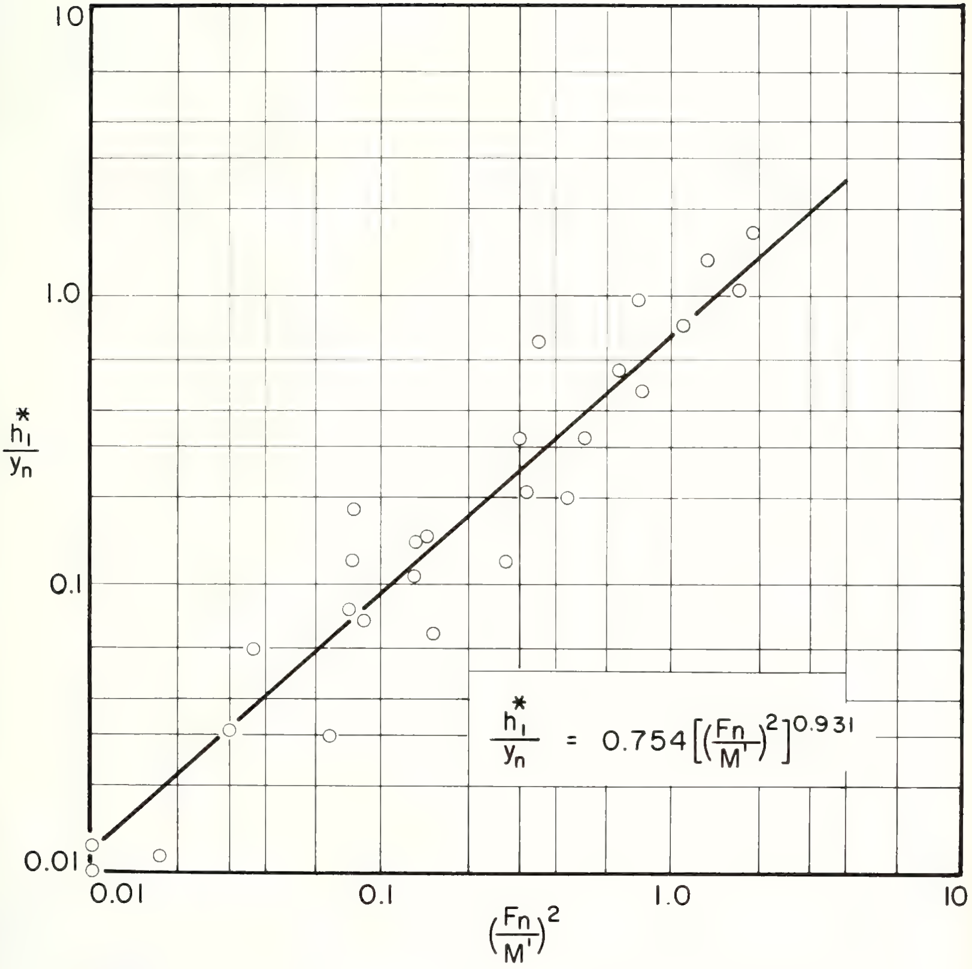


FIGURE 7-8-1 BACKWATER RATIO, GEOMETRY VI ROUGH BOUNDARY

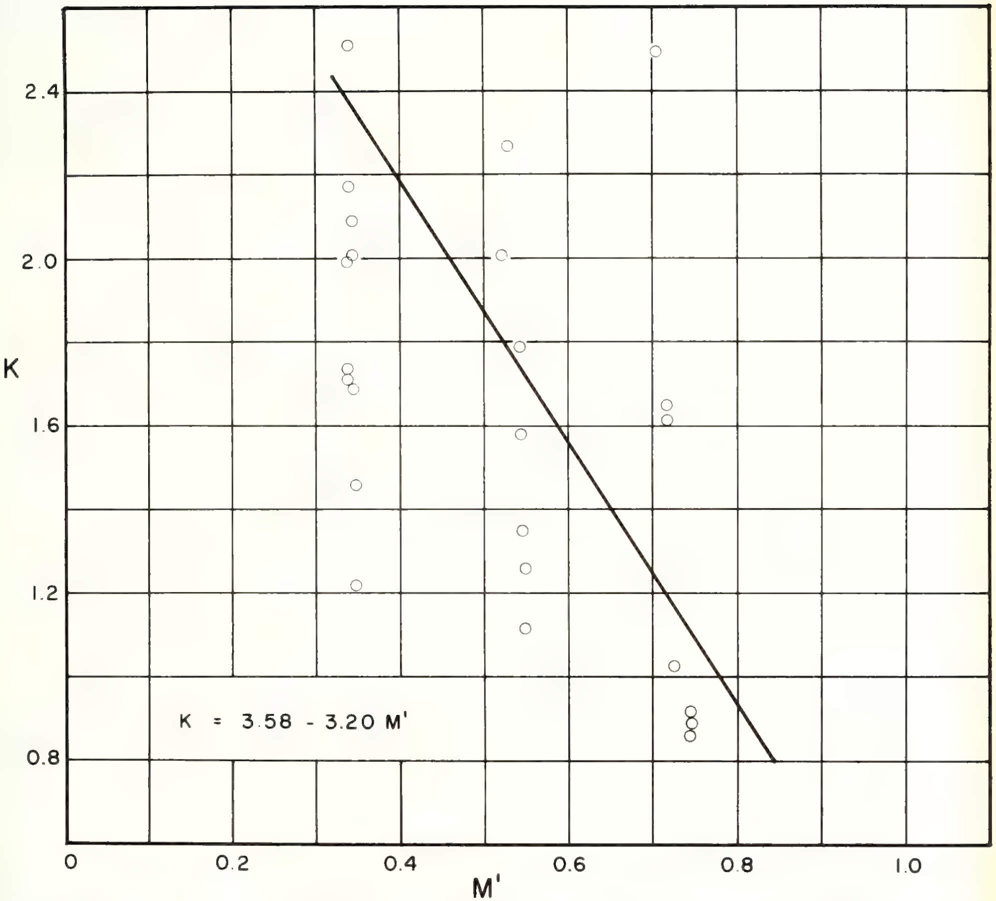


FIGURE 7-8-2 HEAD LOSS COEFFICIENT, GEOMETRY VI
ROUGH BOUNDARY

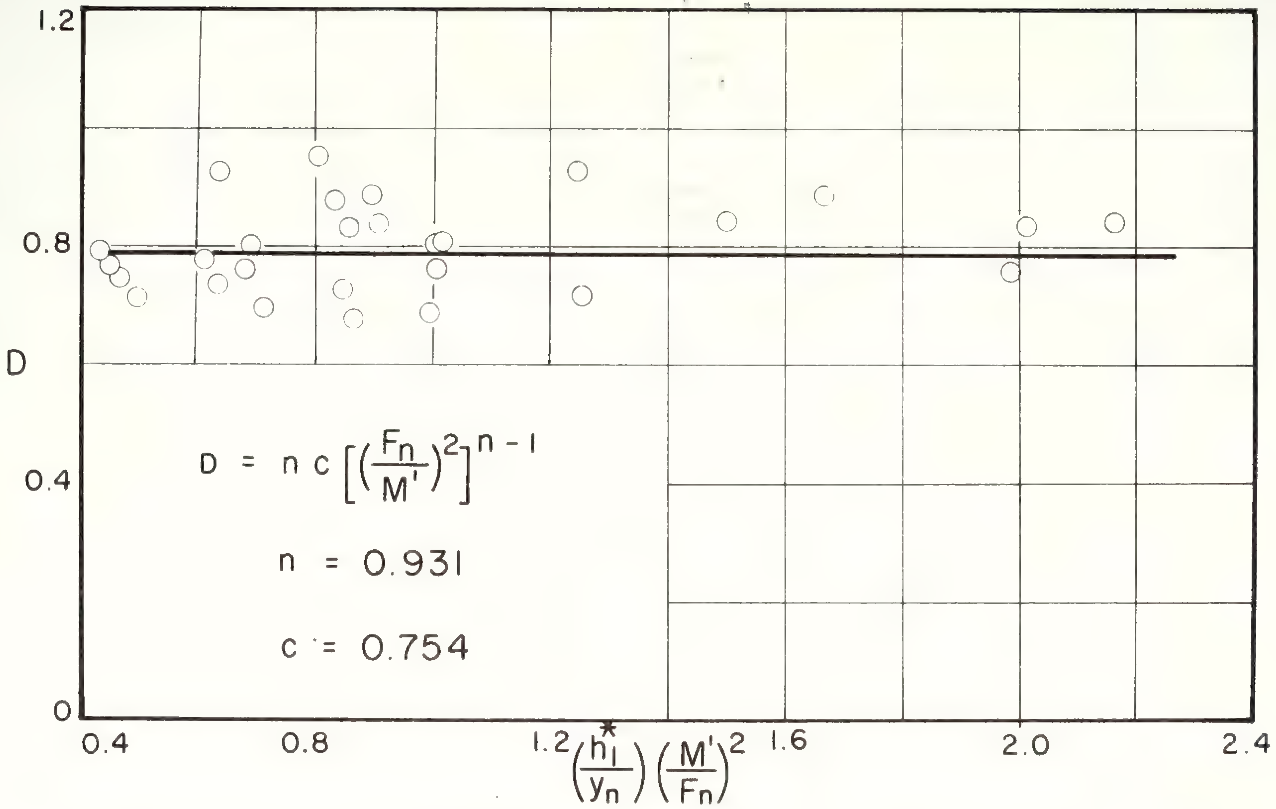


FIGURE 7-8-3 BACKWATER RATIO COEFFICIENT, GEOMETRY VI ROUGH BOUNDARY

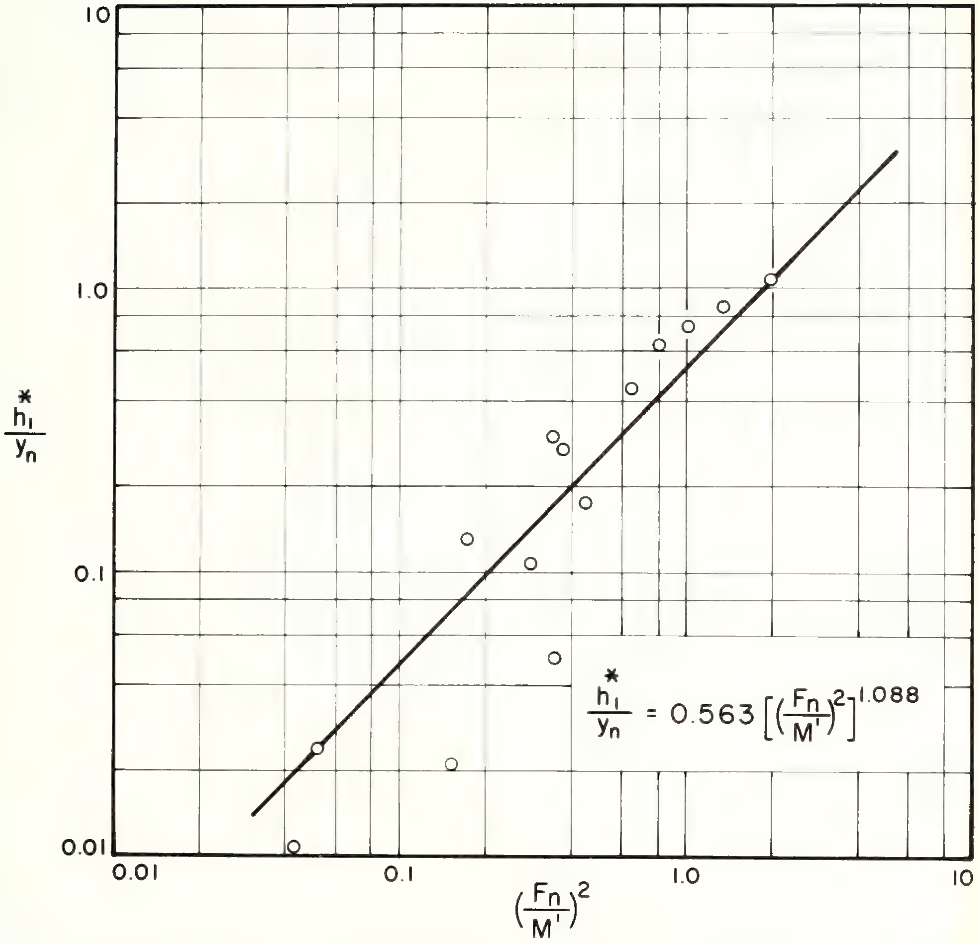


FIGURE 7-9-1 BACKWATER RATIO, GEOMETRY VII
ROUGH BOUNDARY β = 0.00

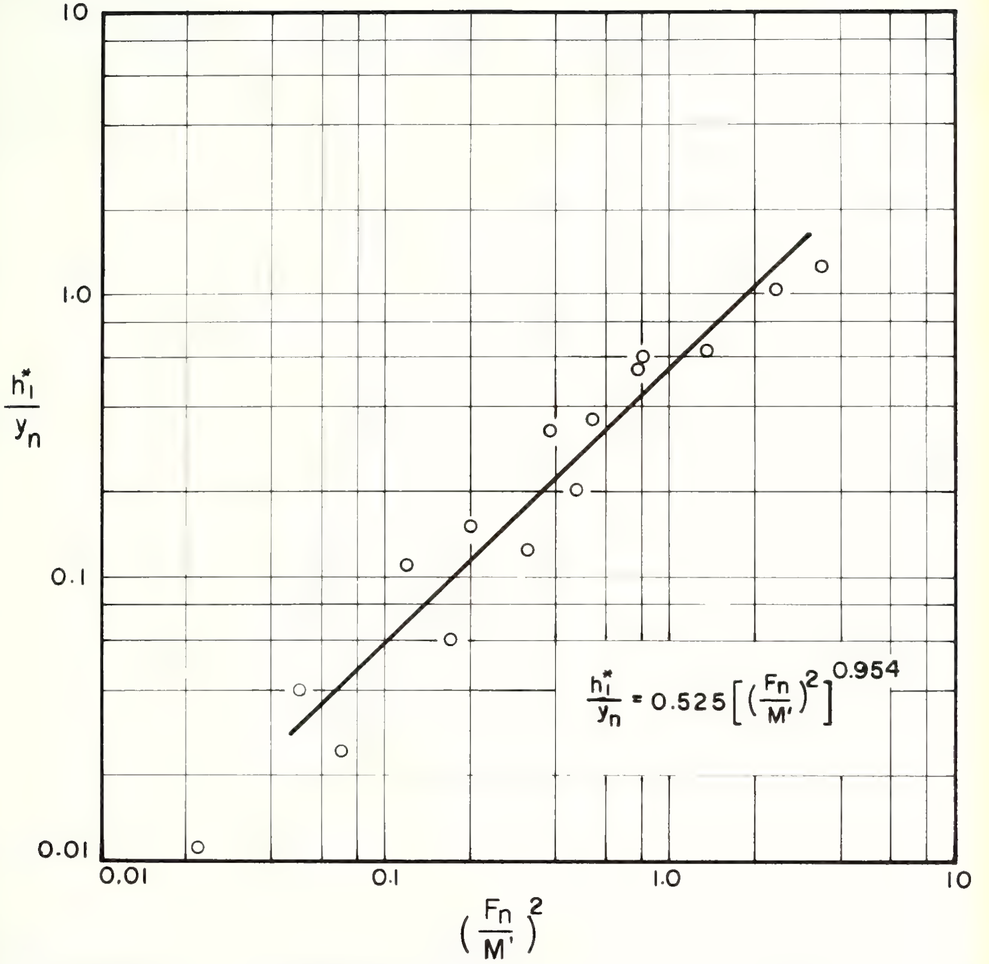


FIGURE 7-9-2 BACKWATER RATIO, GEOMETRY VII

ROUGH BOUNDARY $\beta = 0.3$

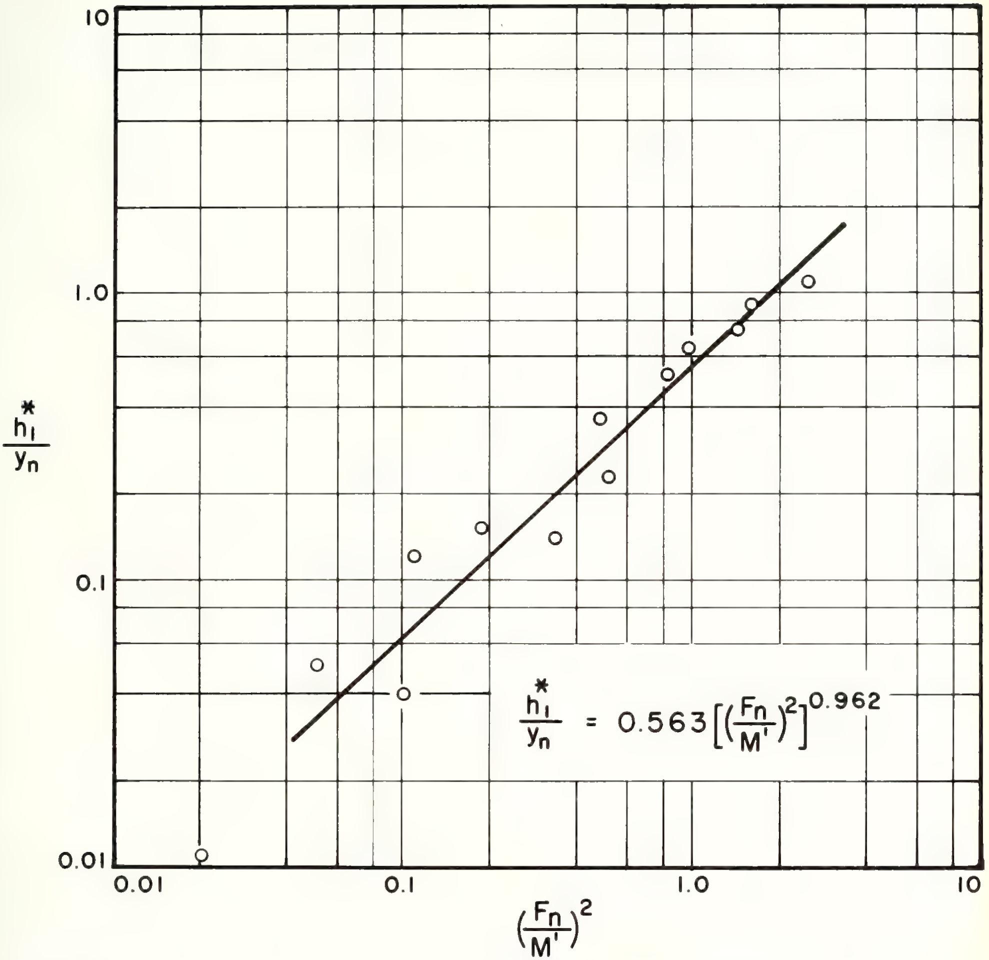


FIGURE 7-9-3 BACKWATER RATIO, GEOMETRY VII

ROUGH BOUNDARIES β = 0.5

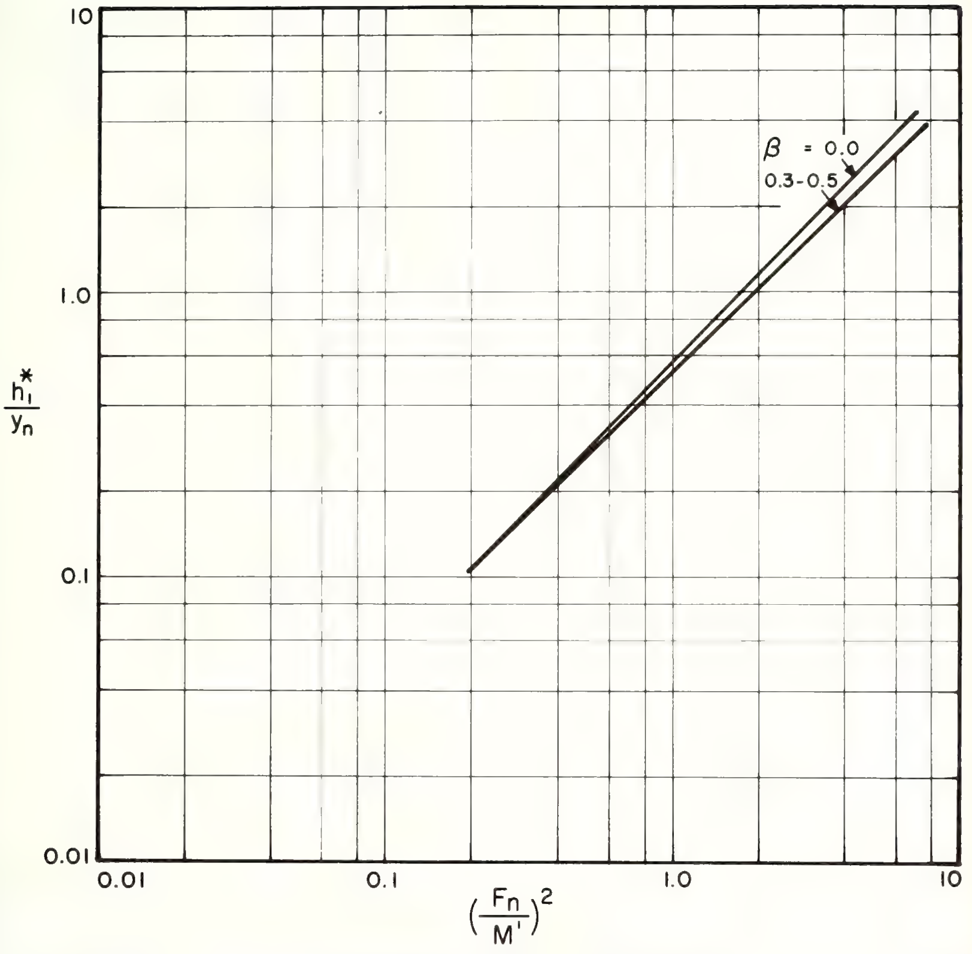


FIGURE 7-9-4 SUMMARY OF BACKWATER RATIO, GEOMETRY VII, ROUGH BOUNDARIES

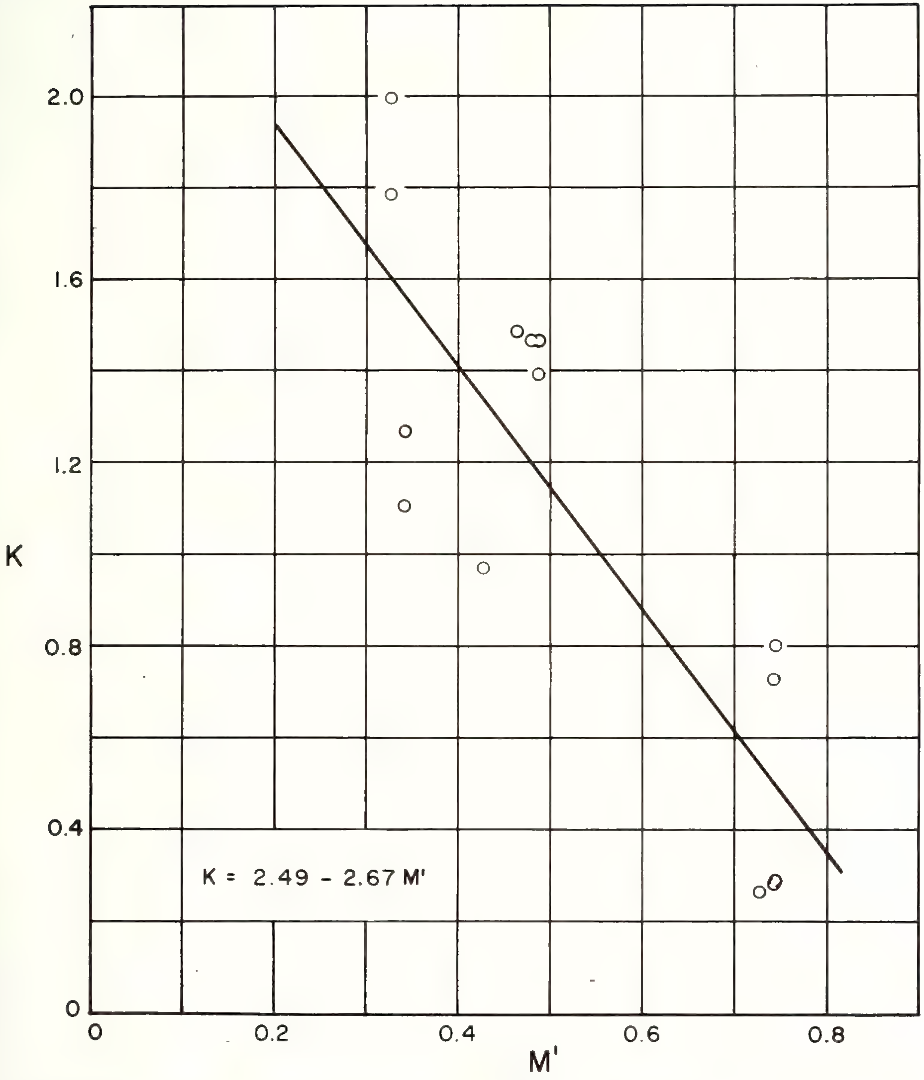


FIGURE 7-9-5 HEAD LOSS COEFFICIENT, GEOMETRY VII ROUGH BOUNDARY, β = 0.00

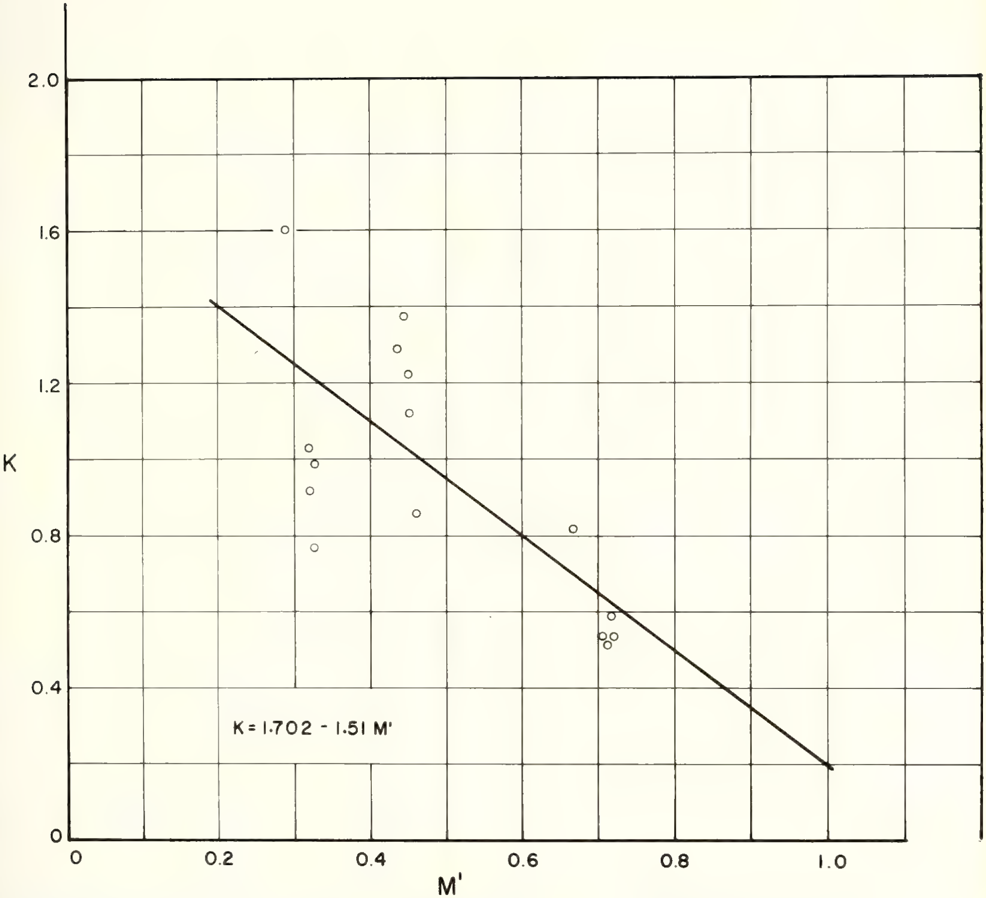


FIGURE 7-9-6 HEAD LOSS COEFFICIENT, GEOMETRY VII
ROUGH BOUNDARY, $\beta = 0.3$

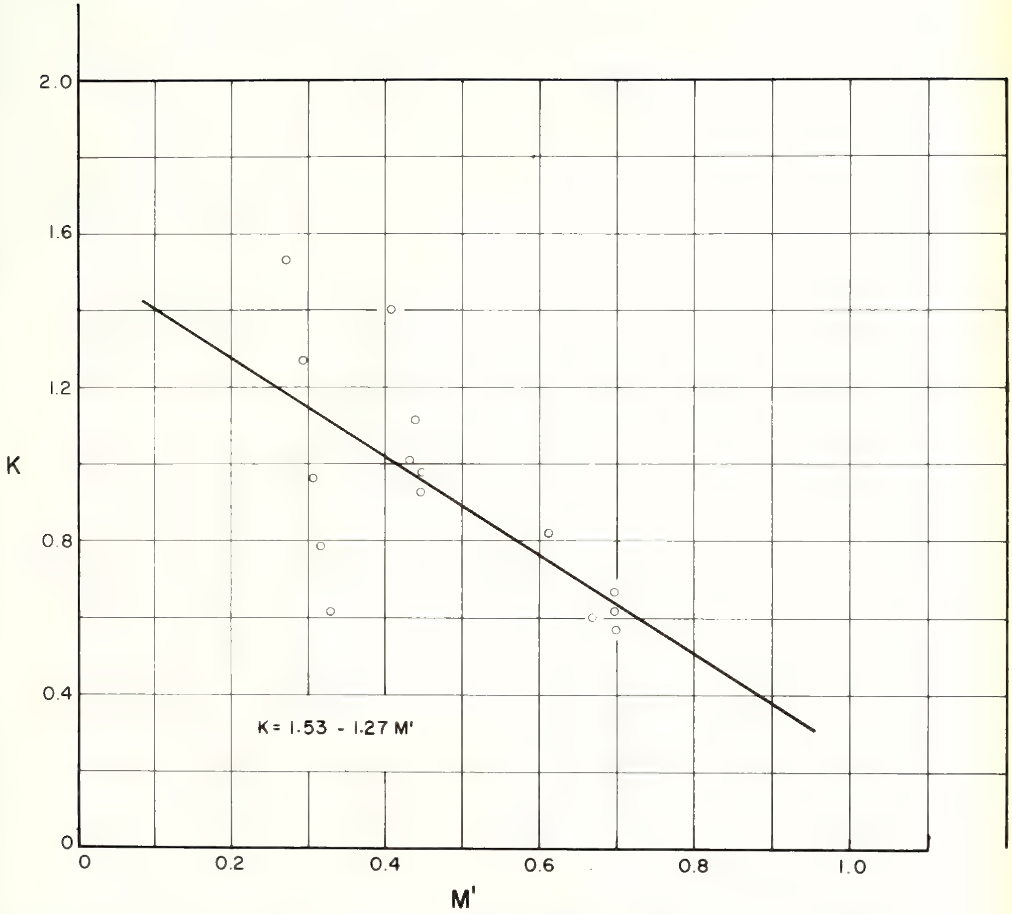


FIGURE 7-9-7 HEAD LOSS COEFFICIENT, GEOMETRY VII
ROUGH BOUNDARY, β = 0.5

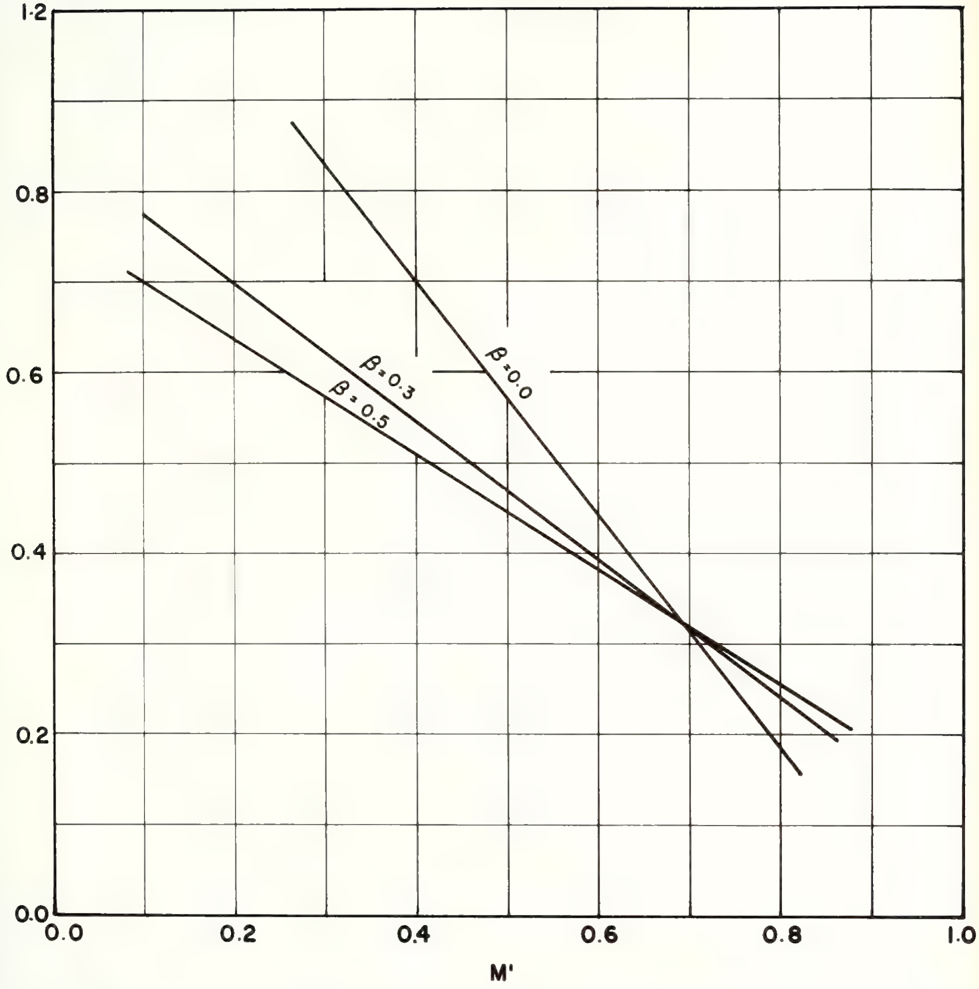


FIGURE 7-9-8 SUMMARY OF HEAD LOSS COEFFICIENT

GEOMETRY VII ROUGH BOUNDARY

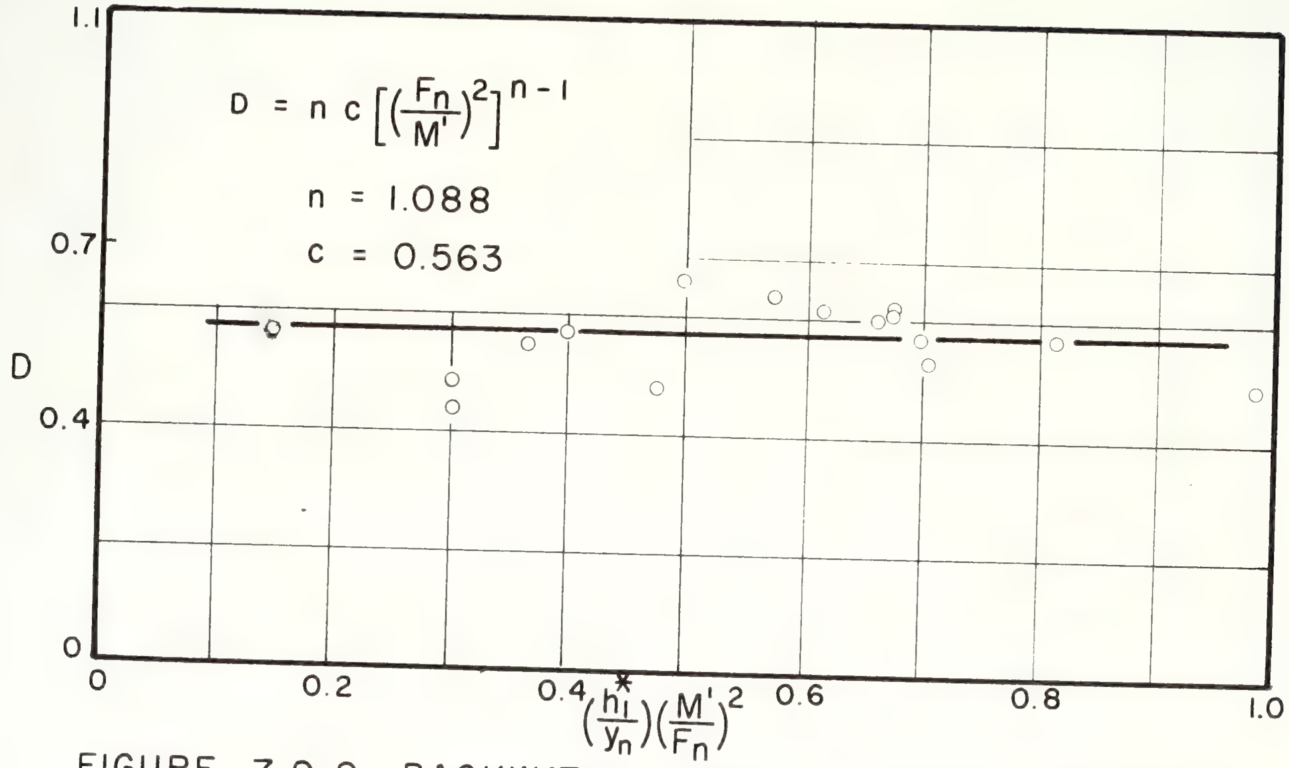


FIGURE 7-9-9 BACKWATER RATIO COEFFICIENT, GEOMETRY VII ROUGH BOUNDARY $\beta = 0.0$

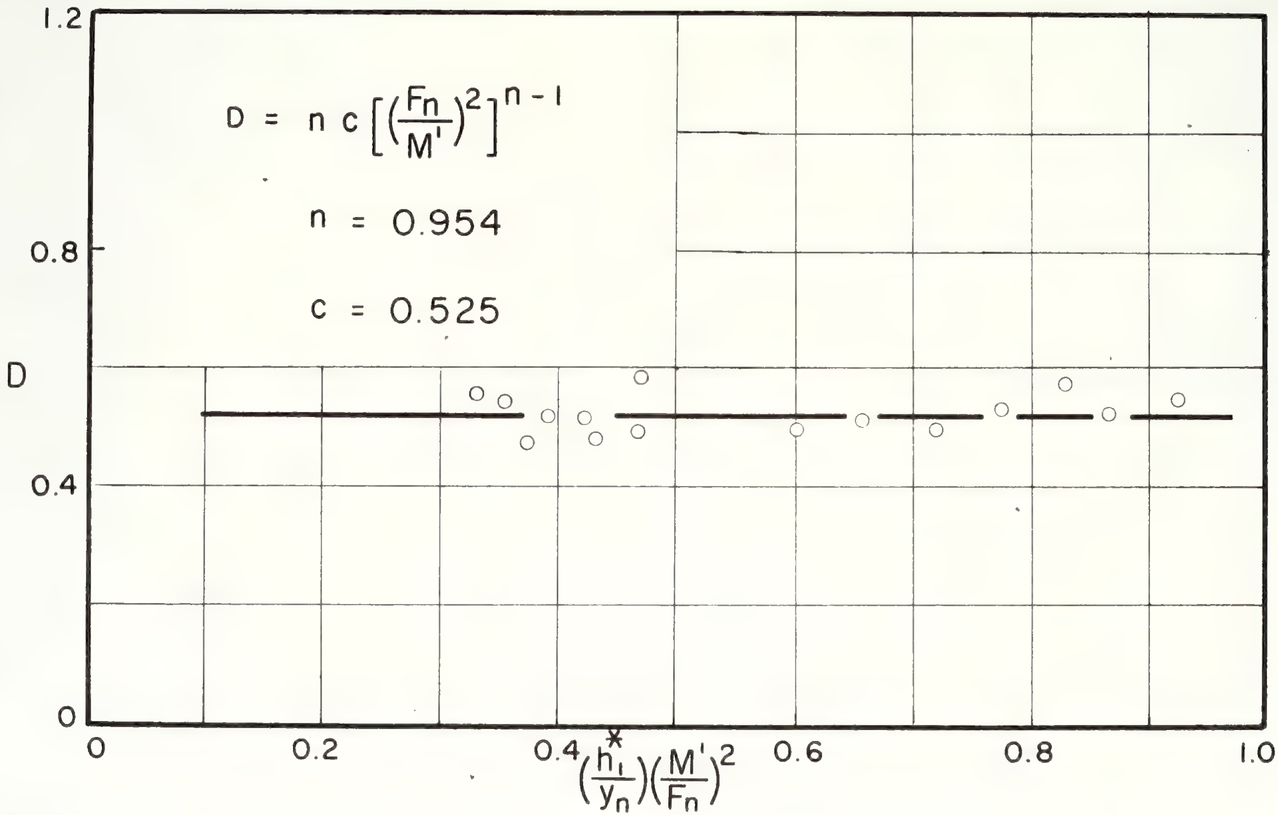


FIGURE 7-9-10 BACKWATER RATIO COEFFICIENT, GEOMETRY VII ROUGH BOUNDARY $\beta = 0.3$

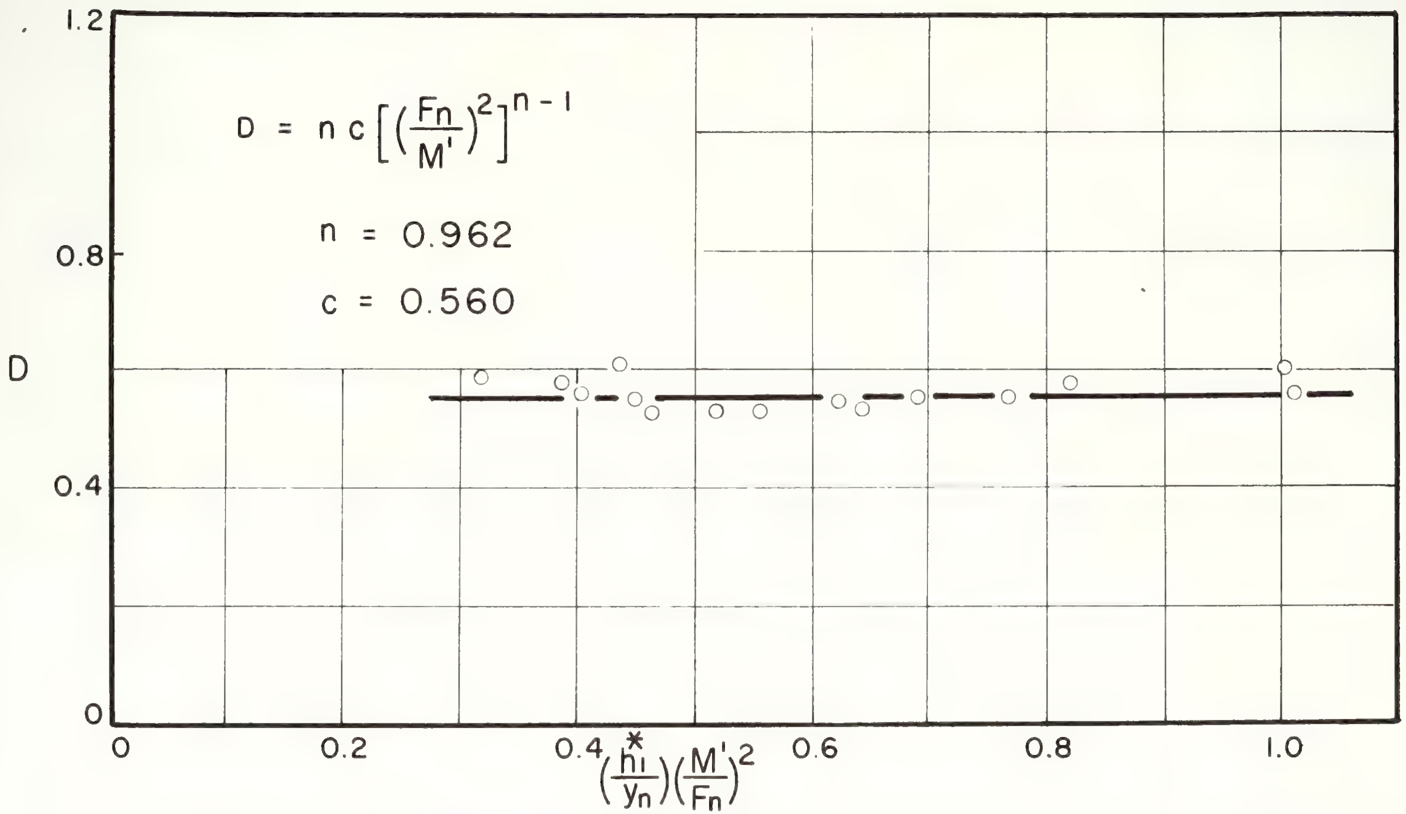


FIGURE 7-9-11 BACKWATER RATIO COEFFICIENT, GEOMETRY VII ROUGH BOUNDARY $\beta = 0.5$

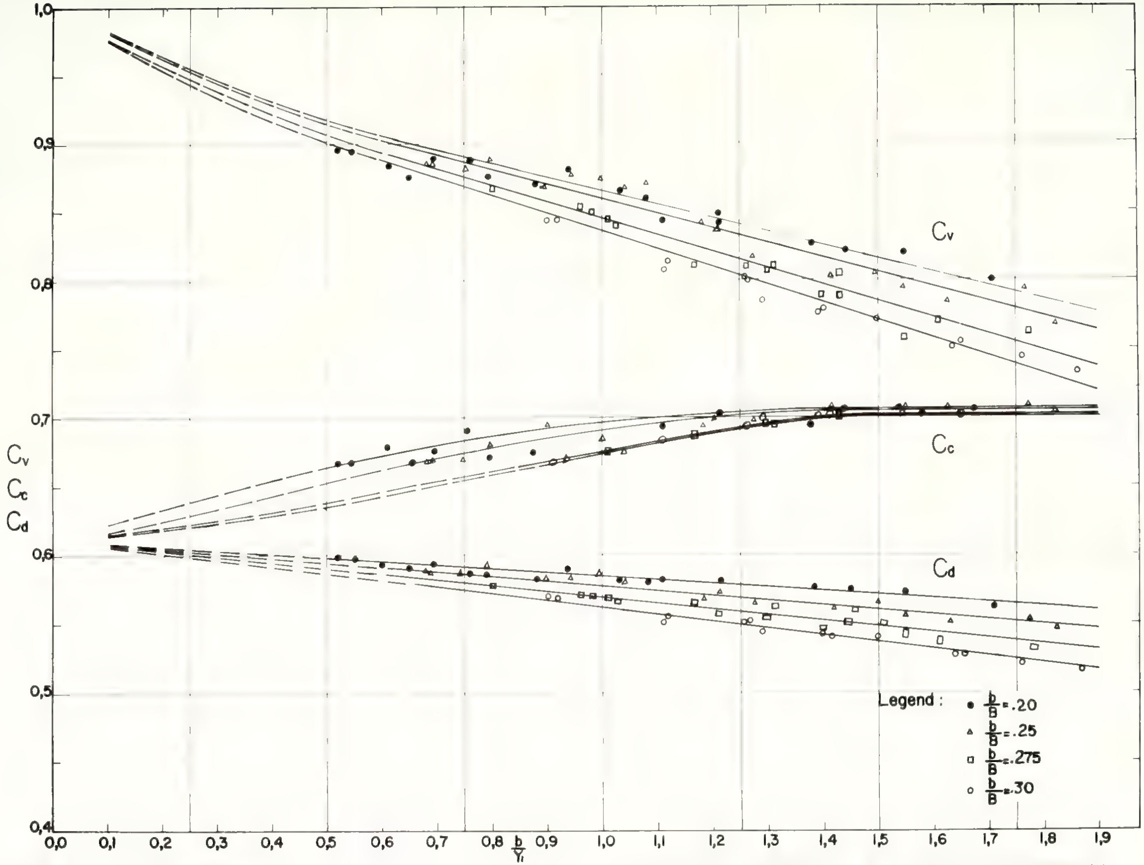


FIG. 8 - 3 - 1 COEFFICIENTS OF VELOCITY, CONTRACTION & DISCHARGE. SUBMERGED INLET BUT UNSUBMERGED DISCHARGE JET.

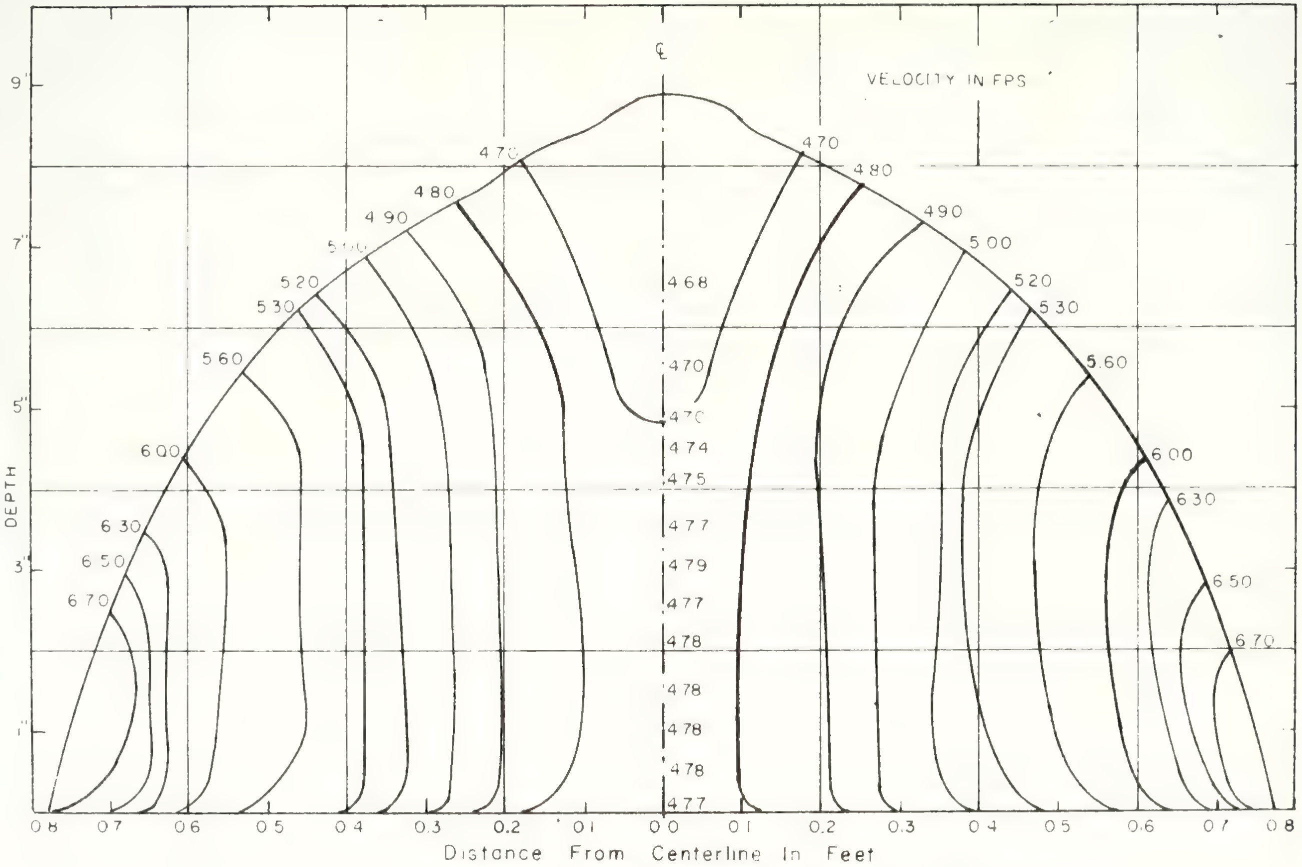


FIG 8-3-2 ISOVELOCITY CURVES AT VENA CONTRACTA

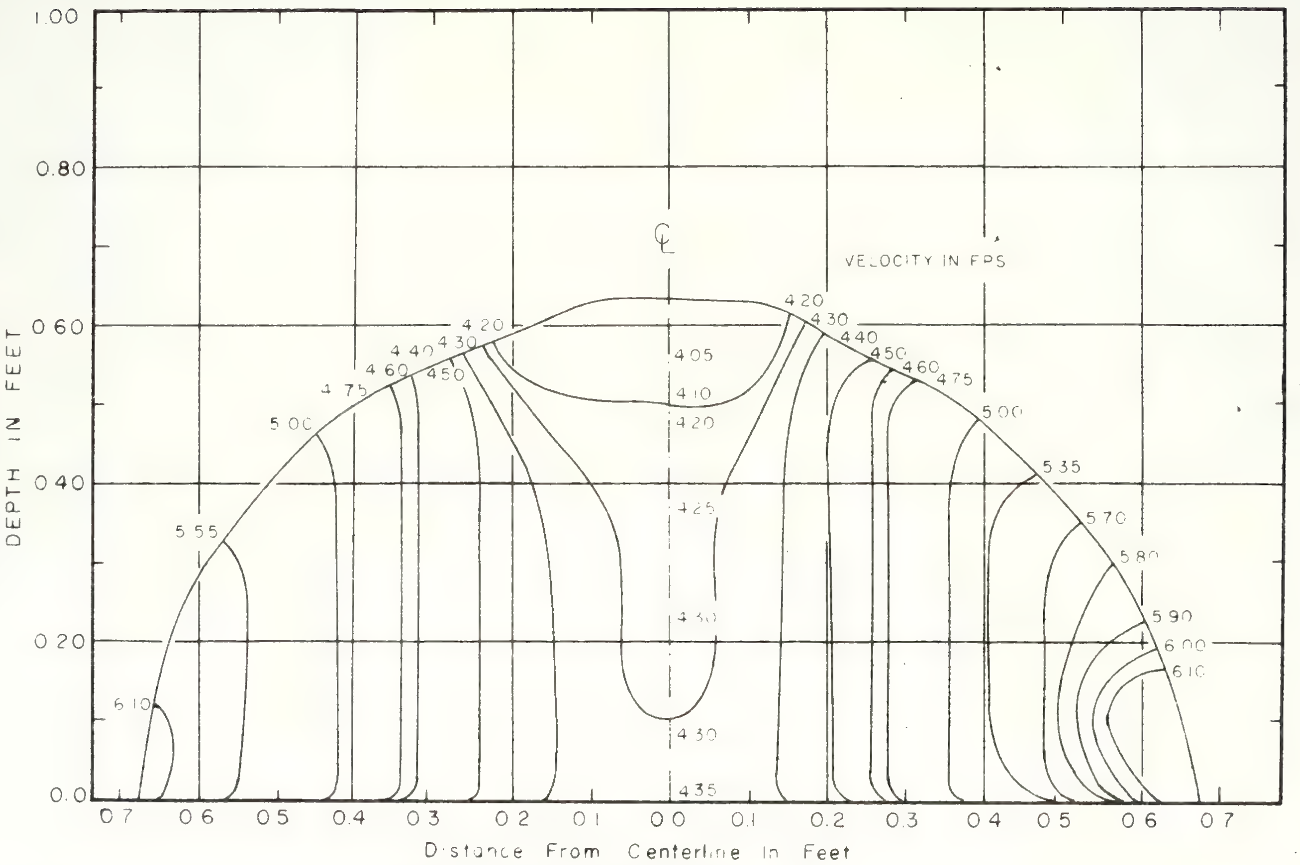


FIG. 8-3-3 ISOVELOCITY CURVES FOR CROSS SECTION AT VENA CONTRACTA

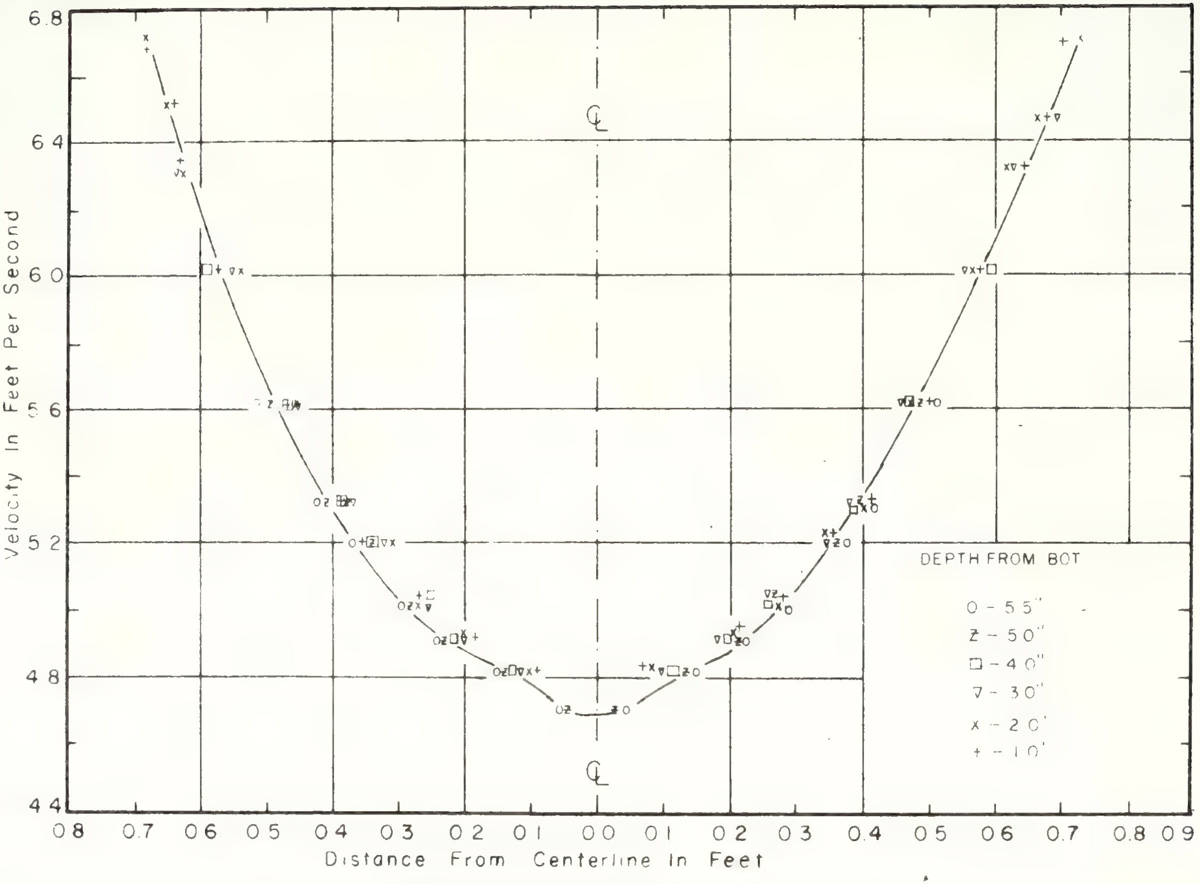


FIG. 8-3-4 VELOCITY DISTRIBUTION AT VENA CONTRACTA

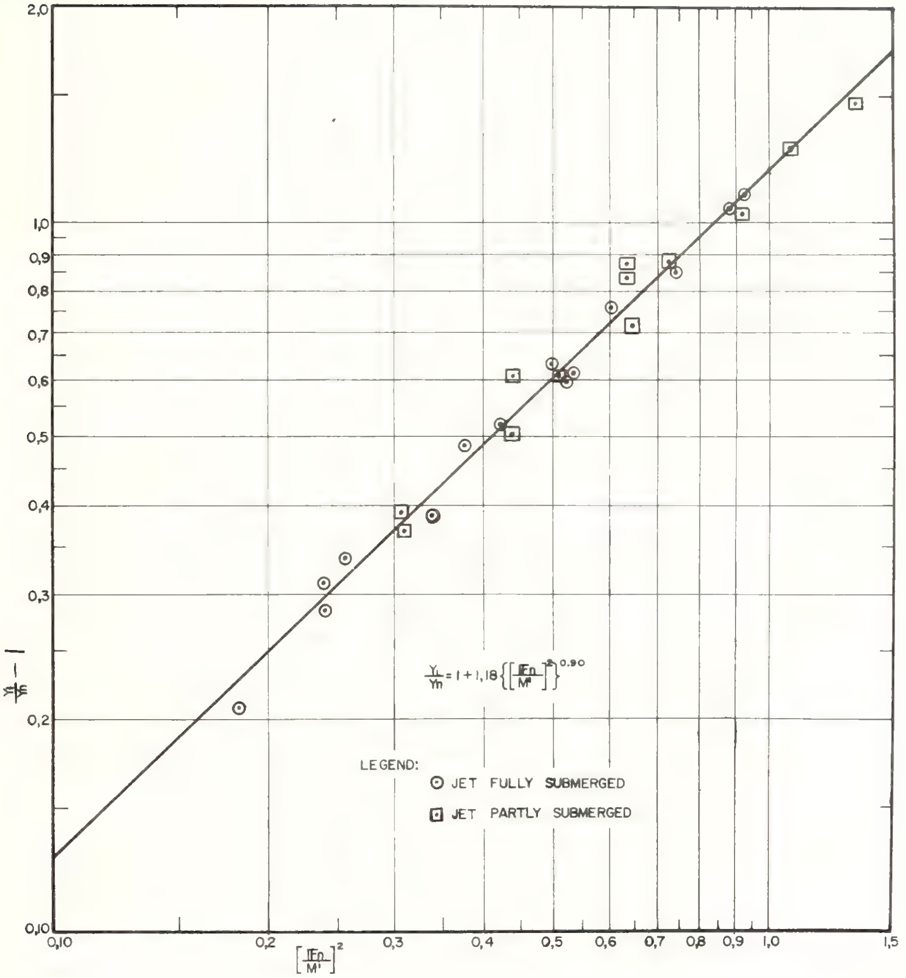


FIG. 8-3-5 GENERALIZED BACKWATER RATIO FOR SUBMERGED INLET. GEOMETRY Ia

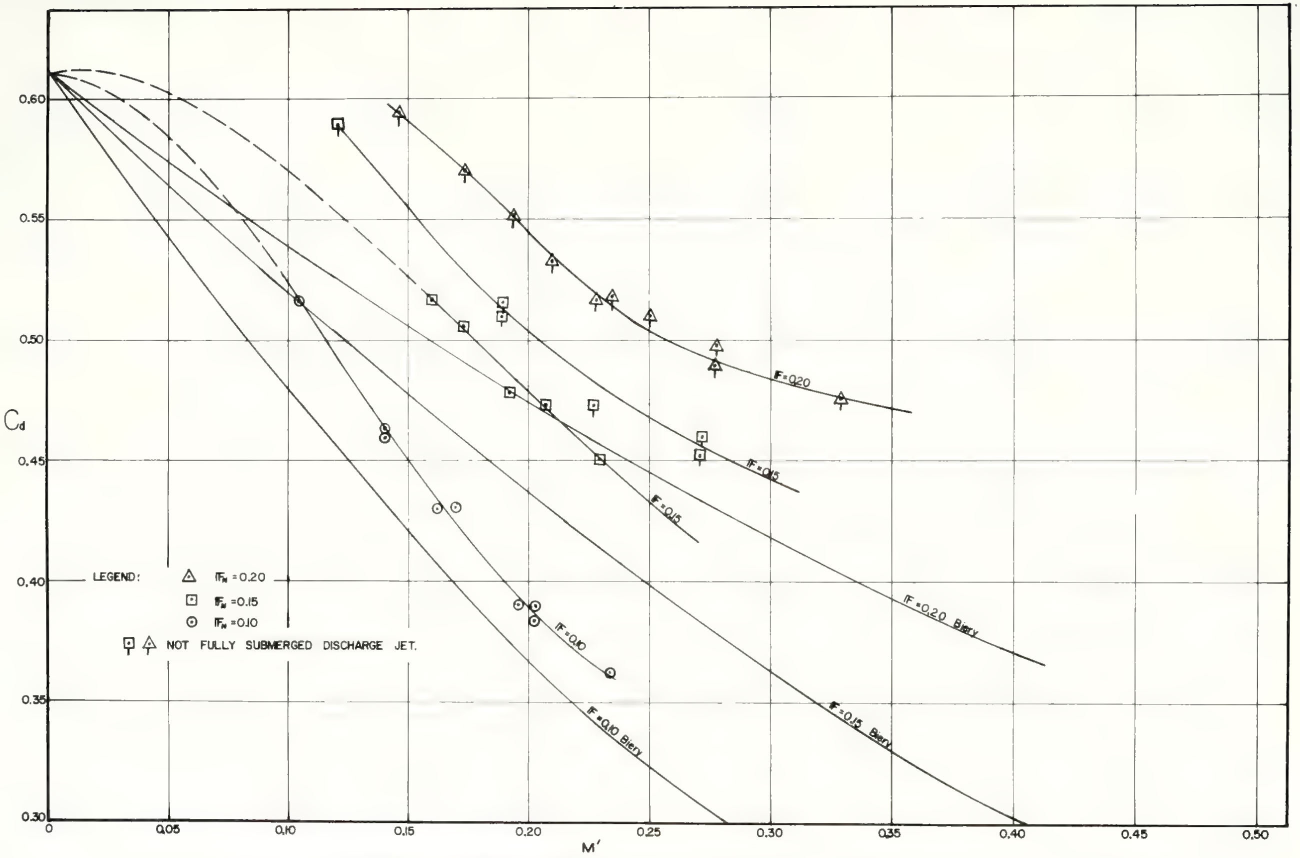


FIG. 8-3-6 DISCHARGE COEFFICIENT Vs CHANNEL OPENING RATIO, SMOOTH BOUNDARIES, GEOMETRY I_a

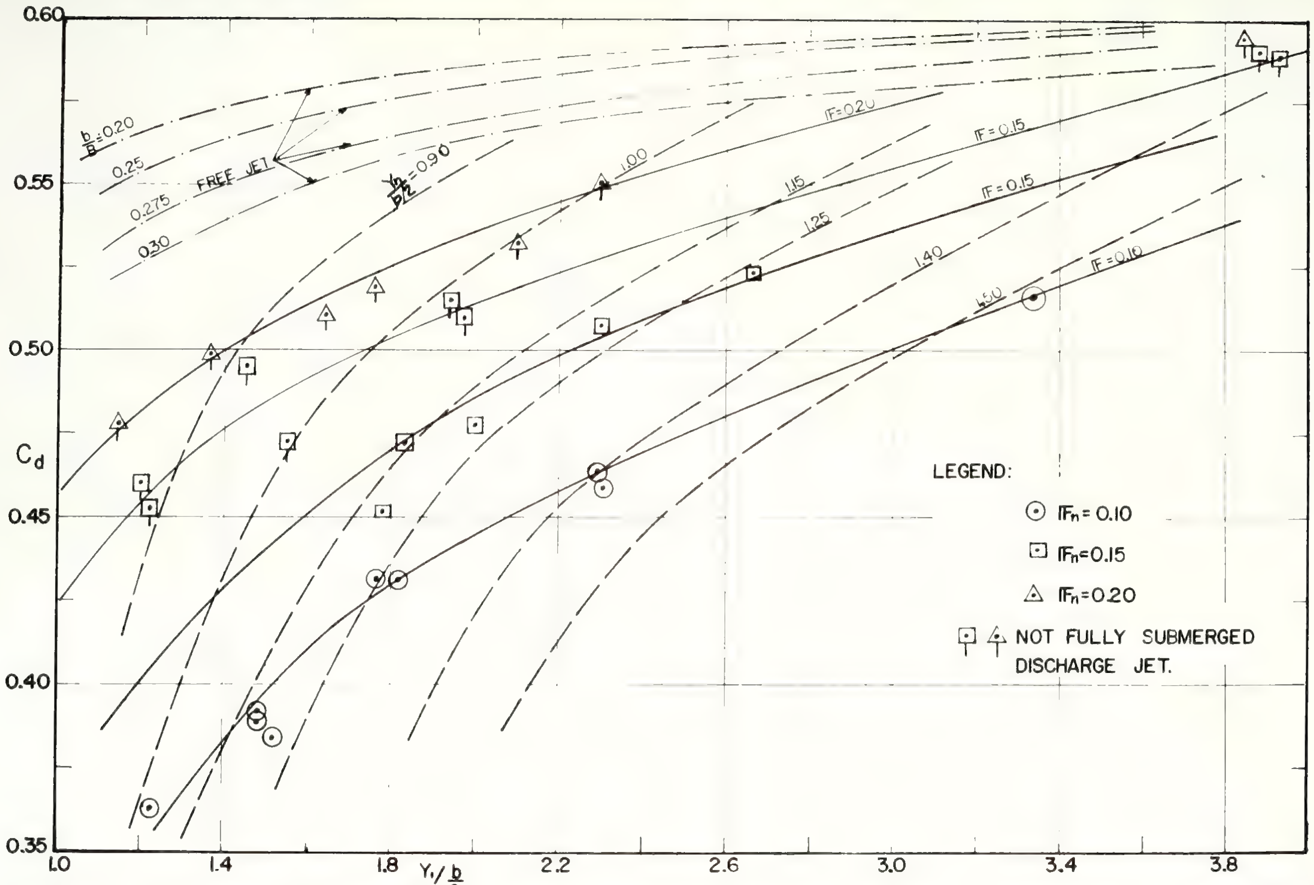


FIG. 8-3-7 DISCHARGE COEFFICIENT FOR FREE & SUBMERGED DISCHARGE & PARTLY SUBMERGED JET. GEOMETRY Ia

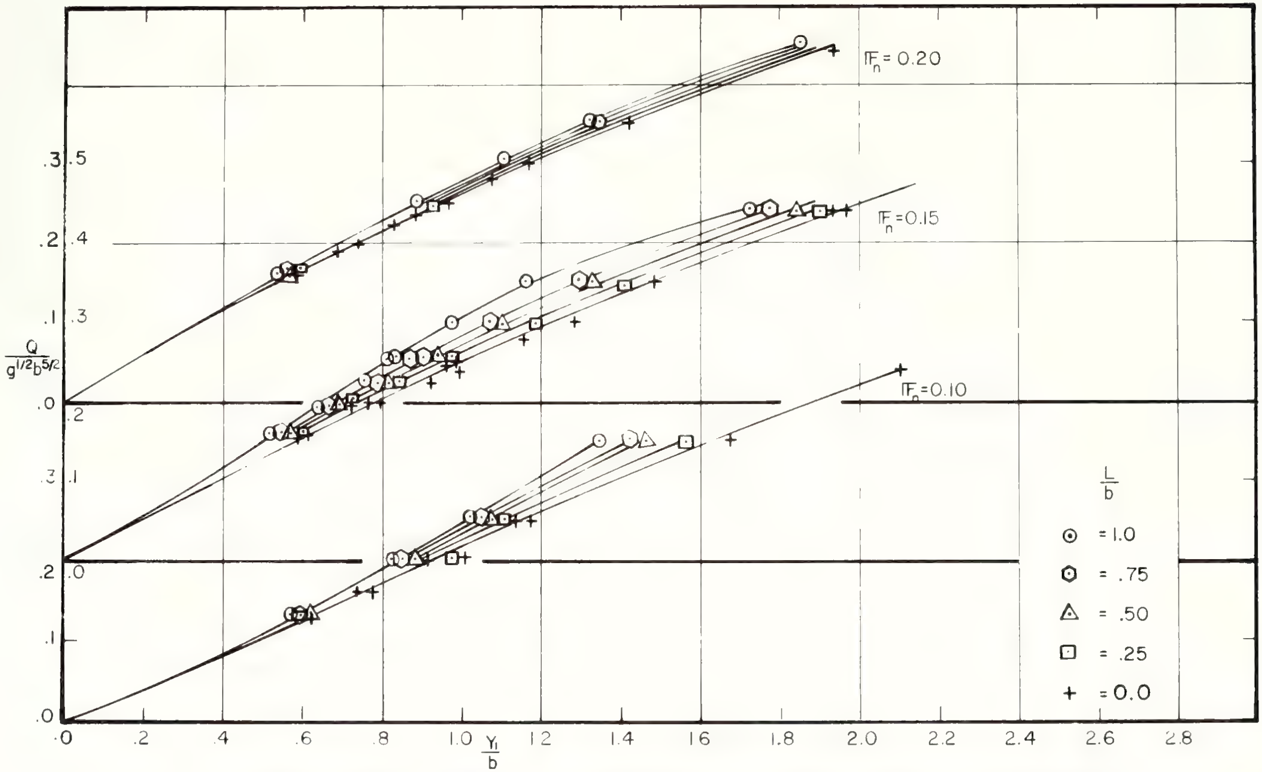


FIG. 8-4-1 DIMENSIONLESS CURVES FOR GEOMETRIES Ia AND Ib. SMOOTH BOUNDARIES

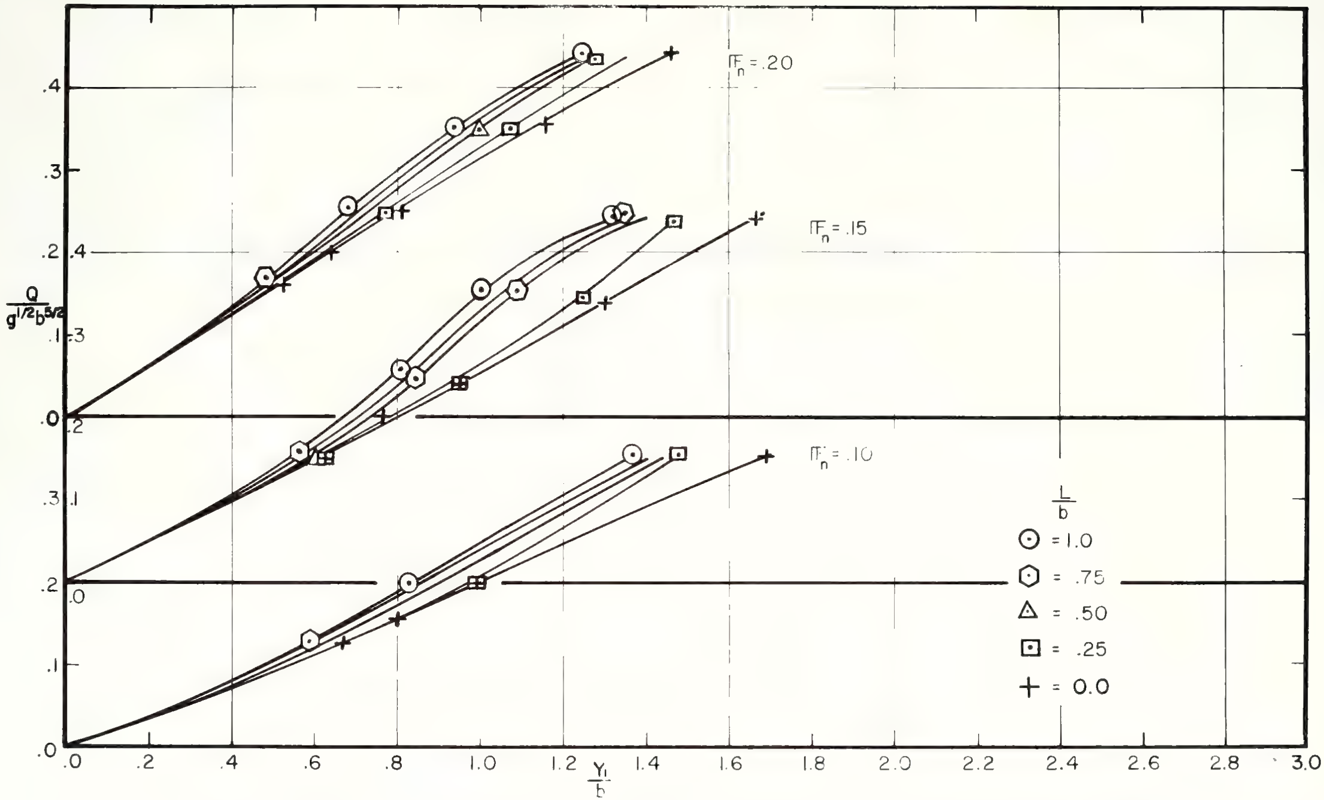


FIG. 8-5-1 DIMENSIONLESS CURVES FOR GEOMETRIES Ia AND Ib. ROUGH BOUNDARIES

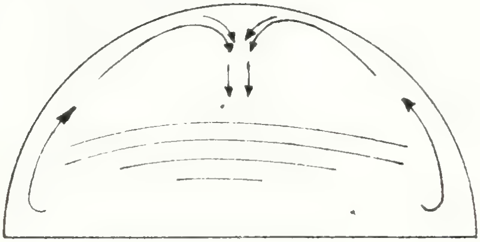


Fig 8-5-2$_a$ Spiral Motion in Barrel Section Downstream of Vena Contracta

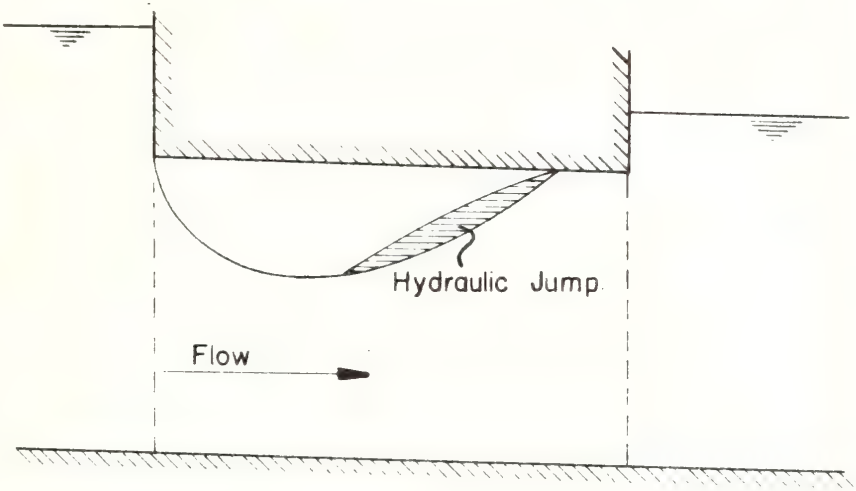


Fig 8-5-2$_b$ Typical Flow Condition Through Constriction

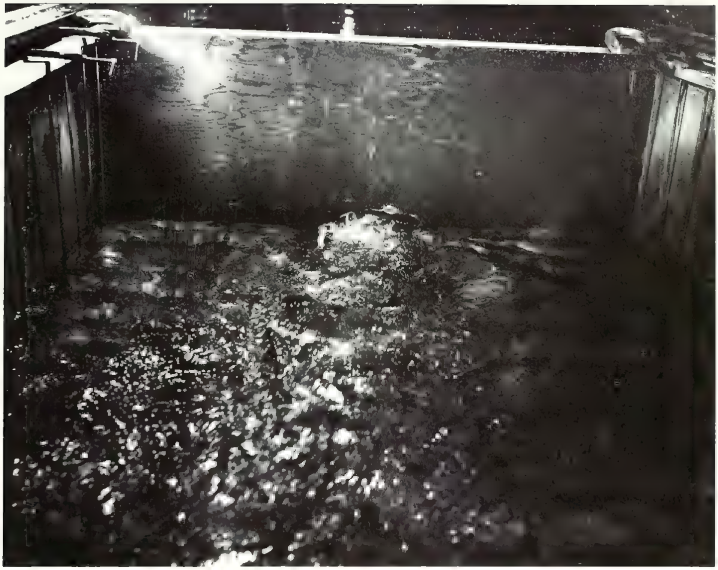


FIG 8-5-3 SLUG FLOW AT BARREL EXIT

FIG 8-5-4 FREE DISCHARGE JET

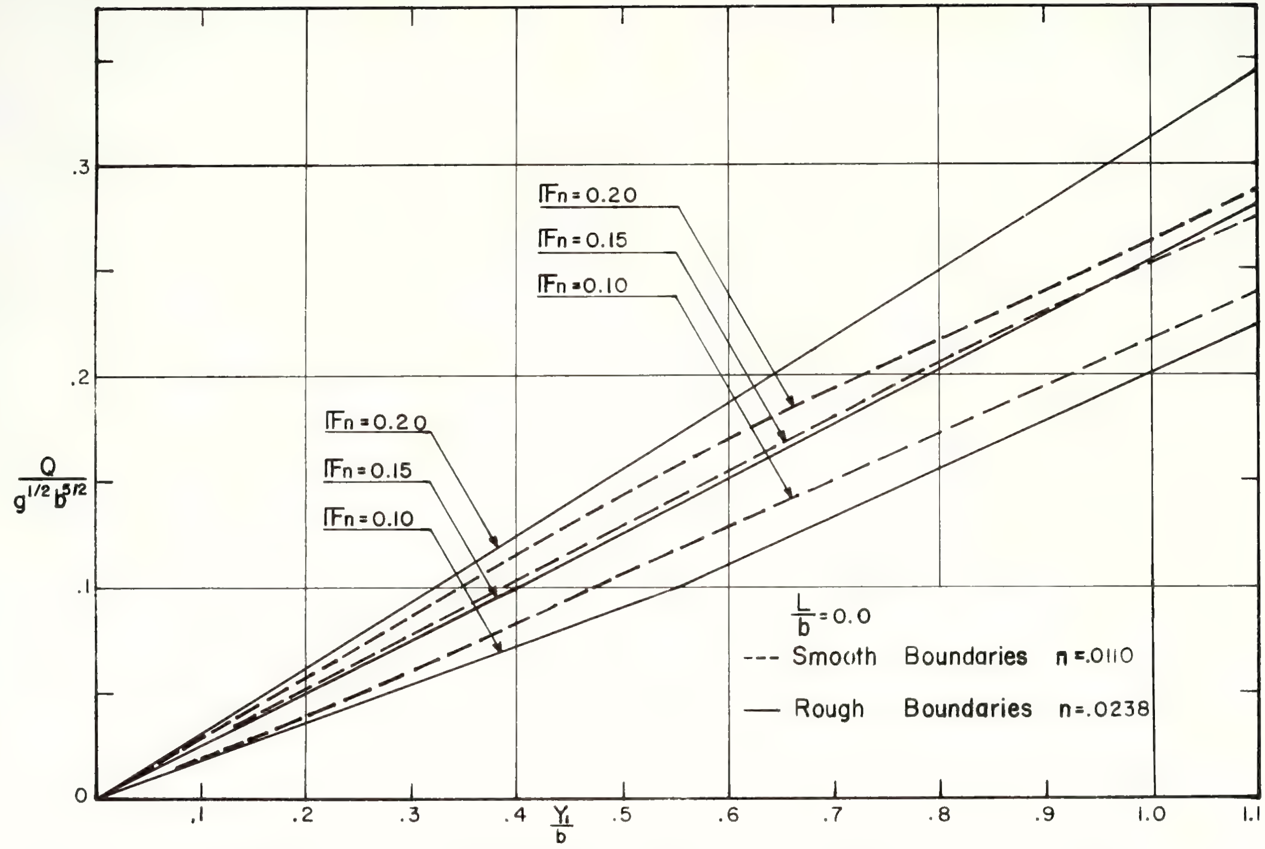


FIG. 8-5-5 Comparison of Dimensionless Curves for Geometry Ia for Smooth and Rough Boundaries

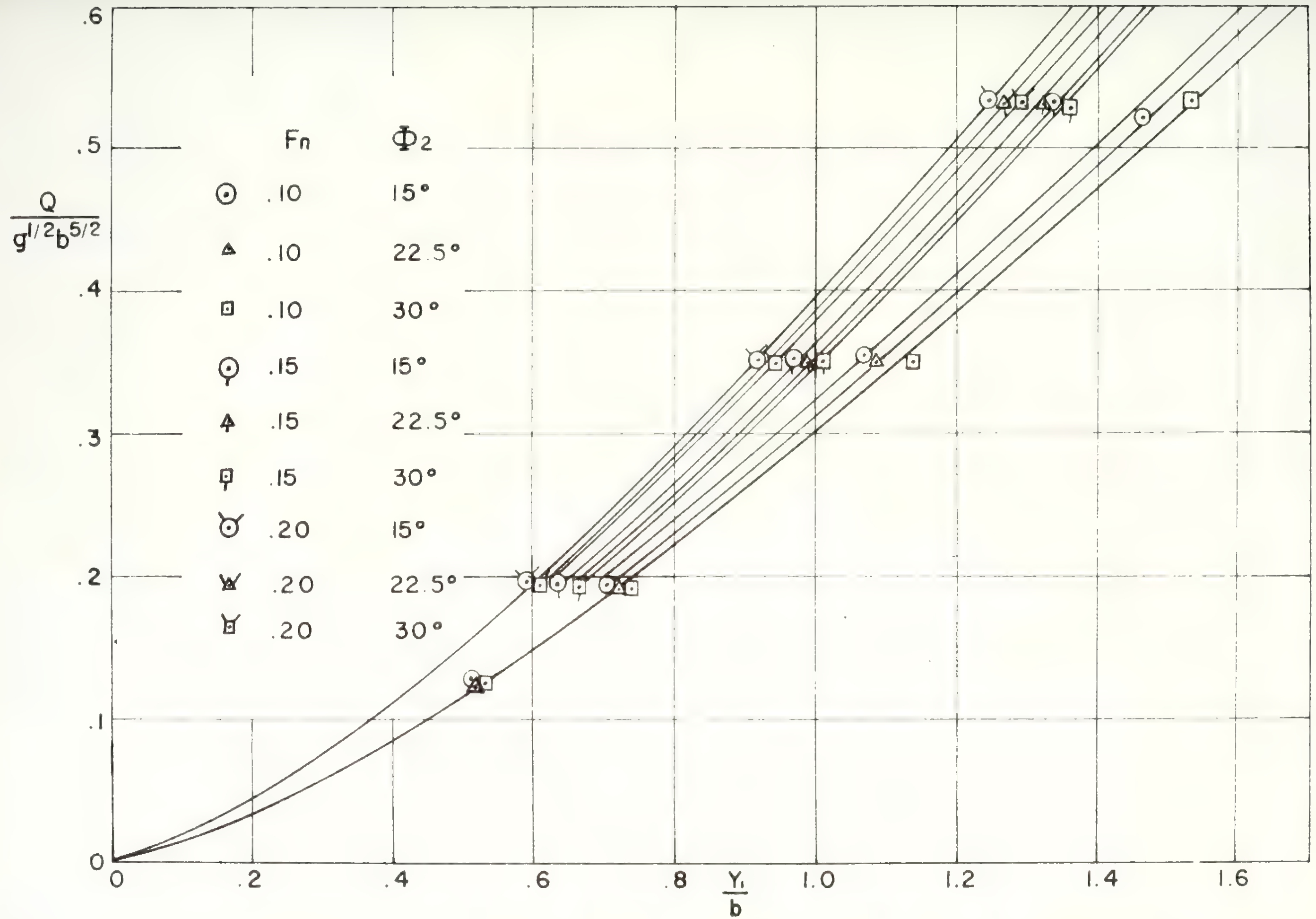


FIG. 8-6-1 Dimensionless Curves for Geometry Vb, Rough Boundaries

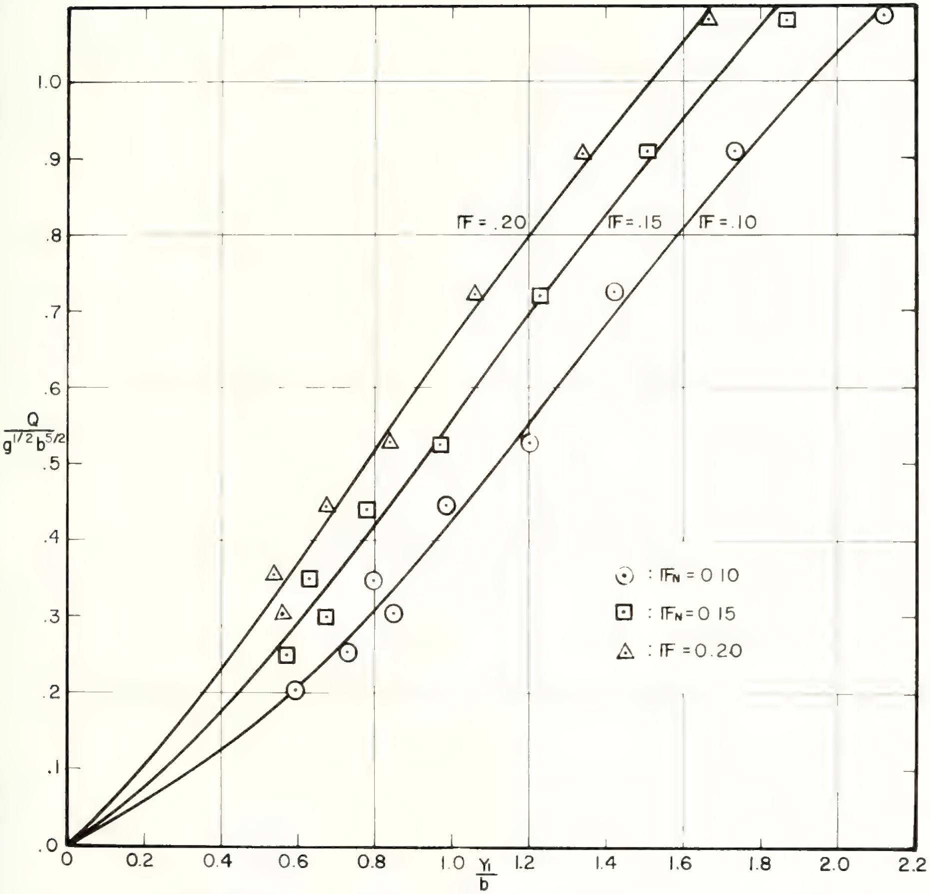


FIG. 8-7-1 DIMENSIONLESS CURVES FOR GEOMETRY VI USING IF_n AS PARAMETER. ROUGH BOUNDARIES

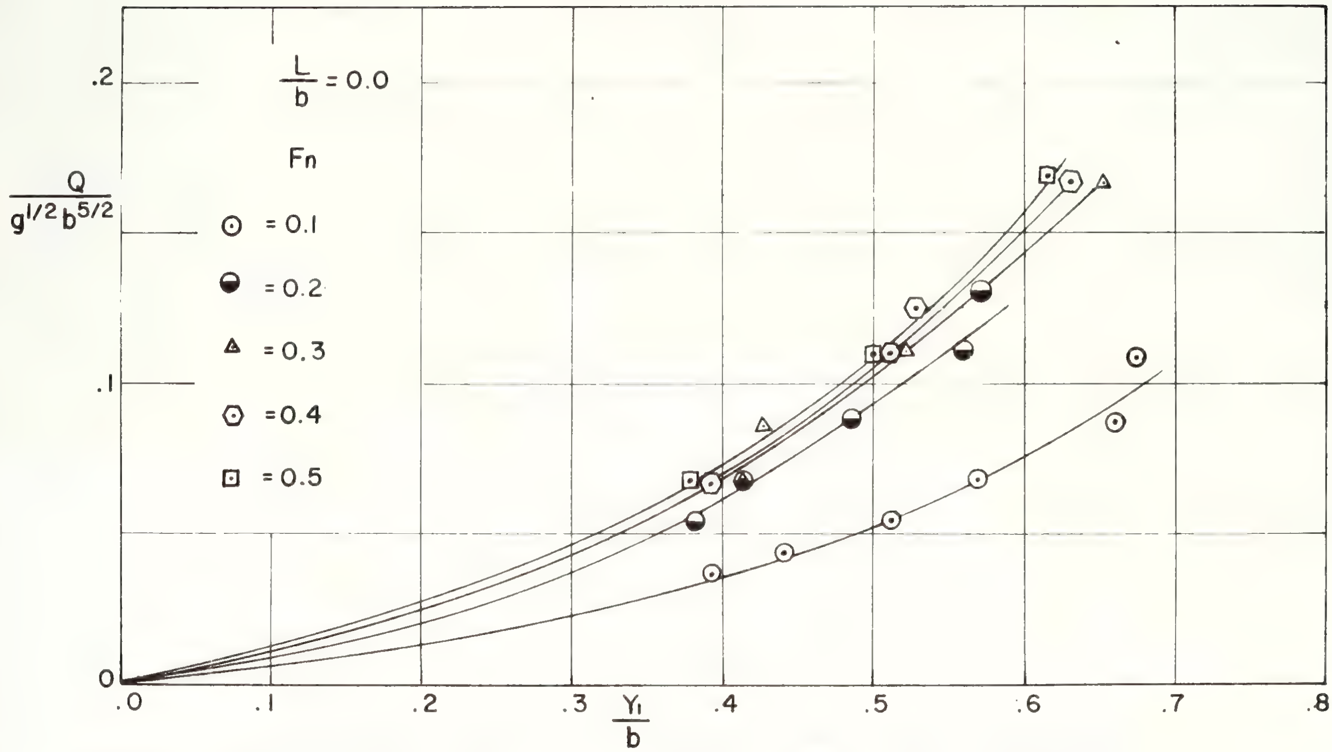


FIG. 8-8-1 Dimensionless Curves for Geometry VII Rough Boundaries

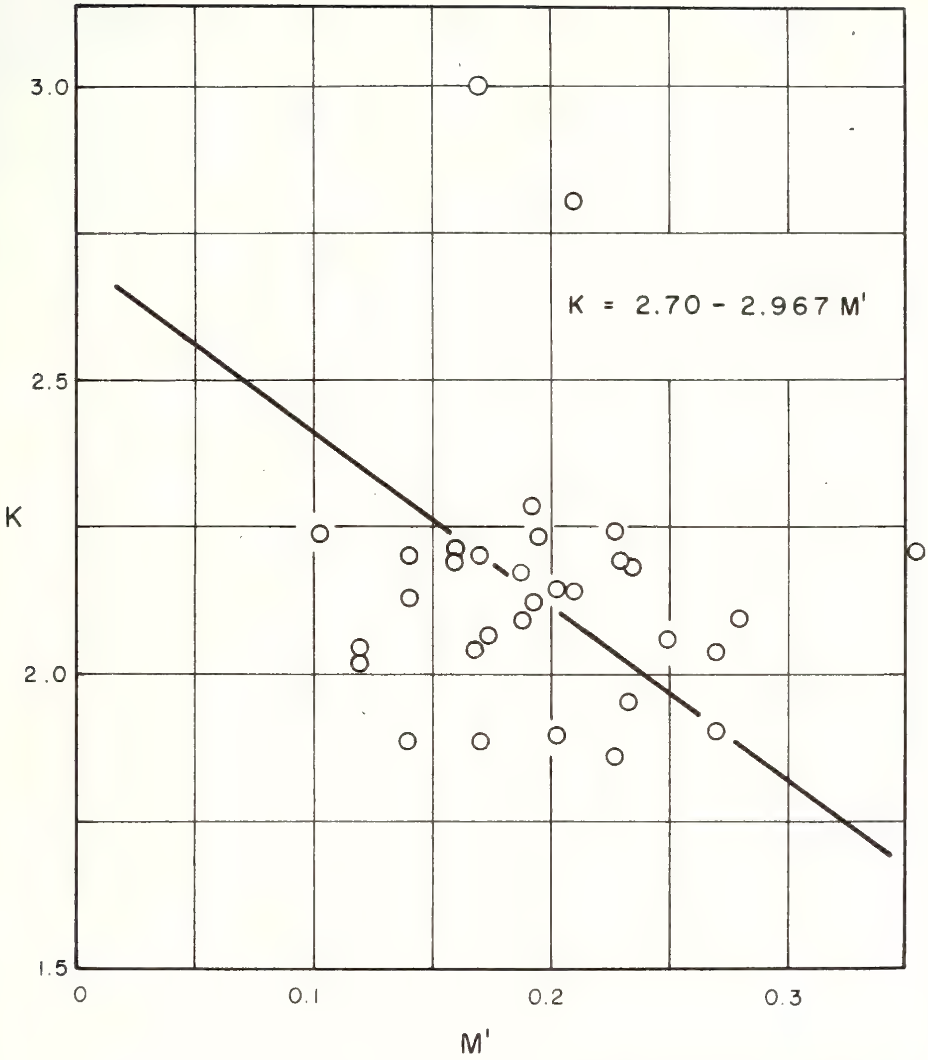


FIG. 8-9-1 HEAD LOSS COEFFICIENT FOR GEOMETRY Ia SMOOTH BOUNDARIES, $\frac{L}{b} = 0.0$

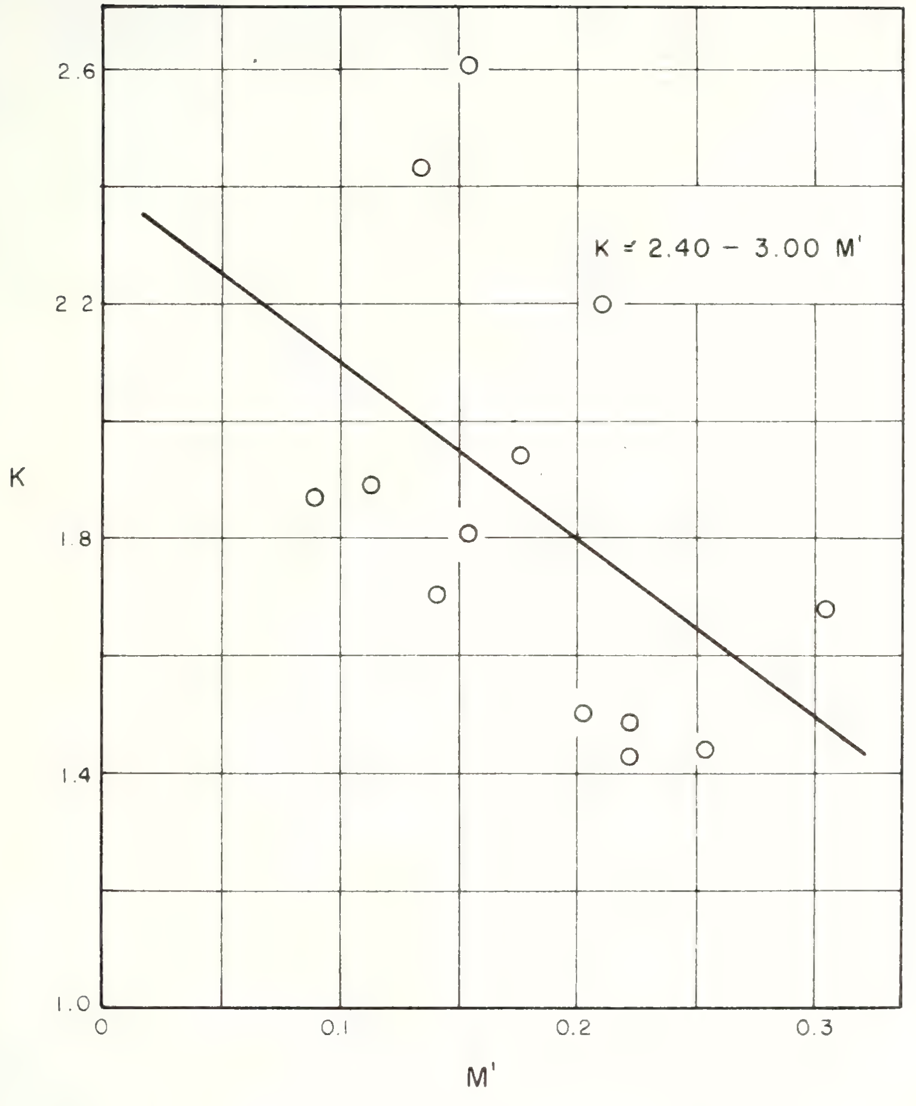


FIG. 8-9-2 HEAD LOSS COEFFICIENT FOR GEOMETRY

Ib SMOOTH BOUNDARIES, $\frac{L}{b} = 0.25$

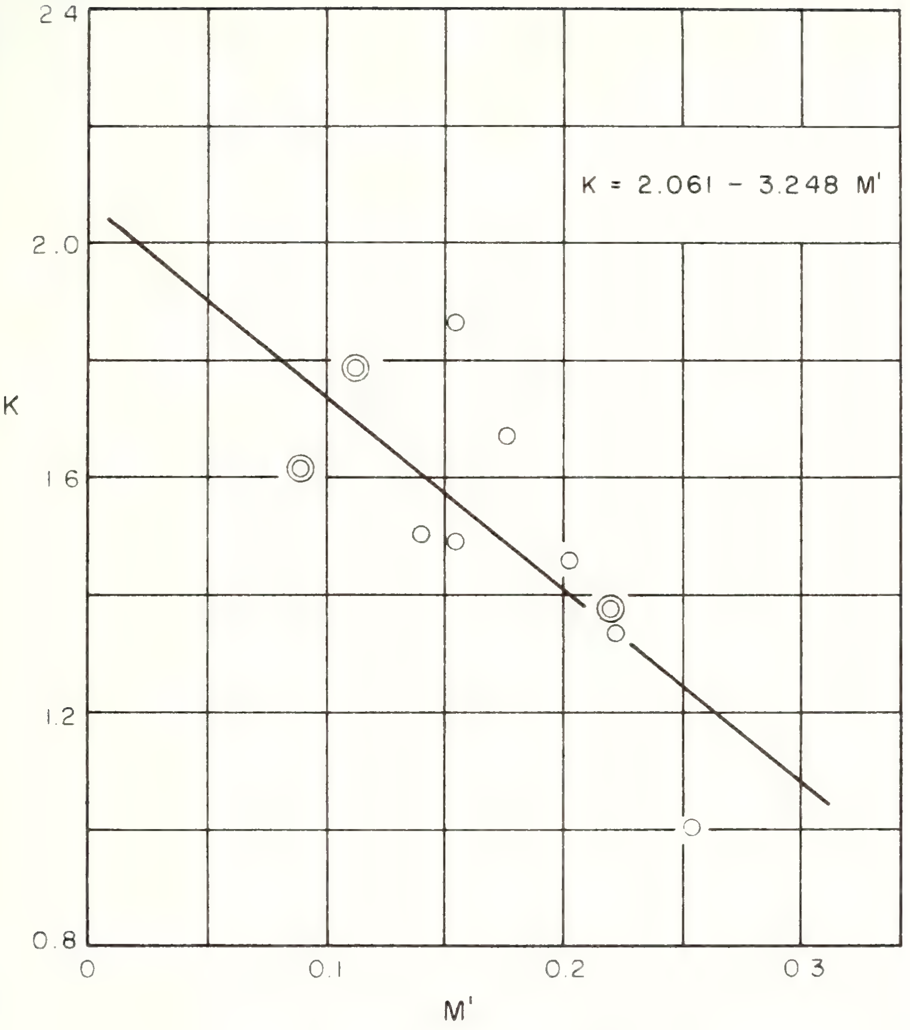


FIG. 8-9-3 HEAD LOSS COEFFICIENT FOR GEOMETRY I_b SMOOTH BOUNDARIES, $\frac{L}{b} = 0.50$

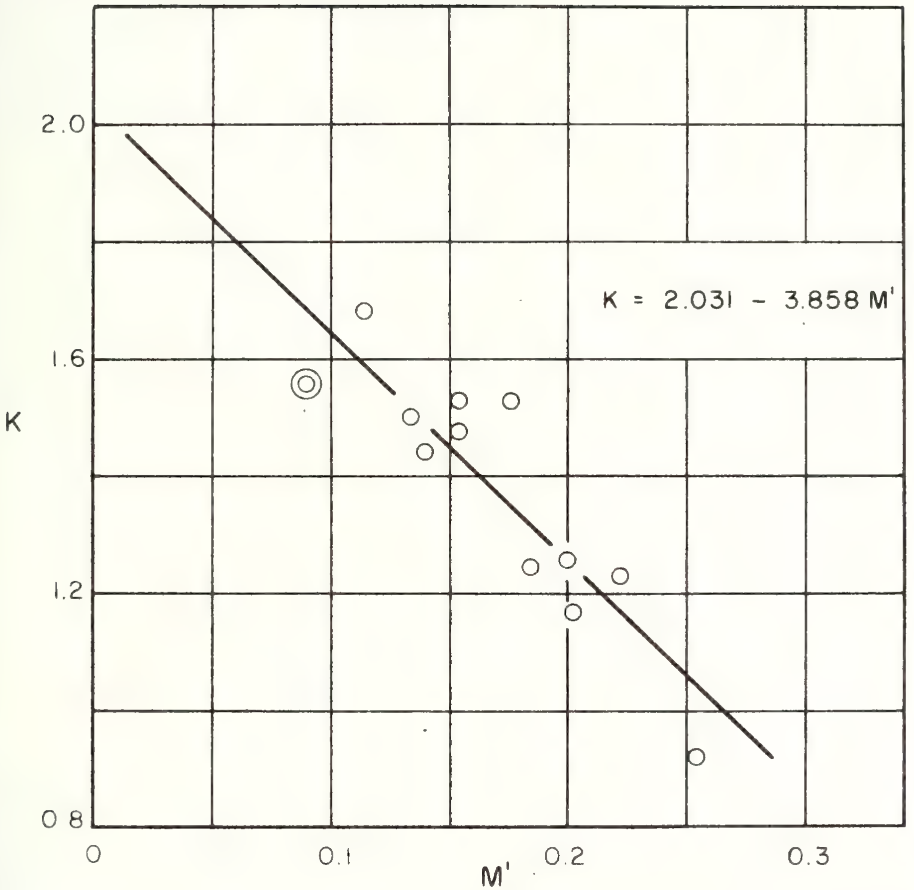


FIG. 8-9-4 HEAD LOSS COEFFICIENT FOR GEOMETRY

I_b SMOOTH BOUNDARIES, $\frac{L}{b}$ = 0.75

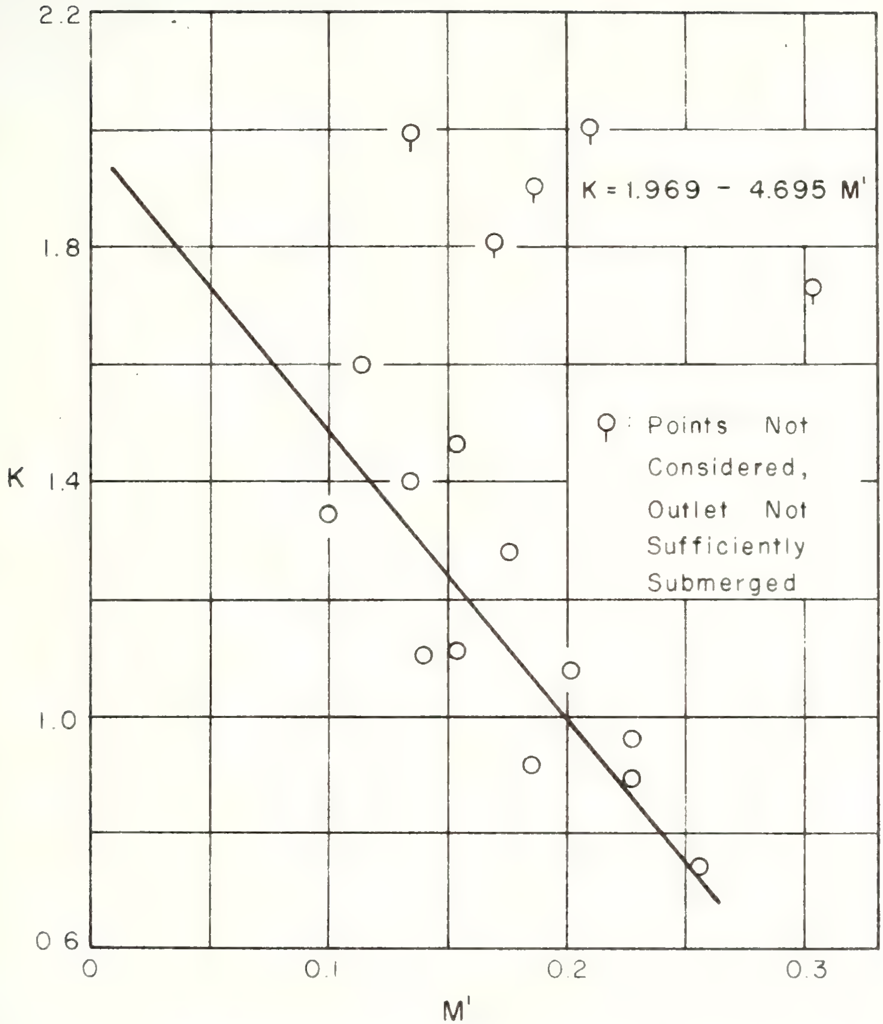


FIG. 8-9-5 HEAD LOSS COEFFICIENT FOR GEOMETRY

I_b, SMOOTH BOUNDARIES, $\frac{L}{b} = 1.00$

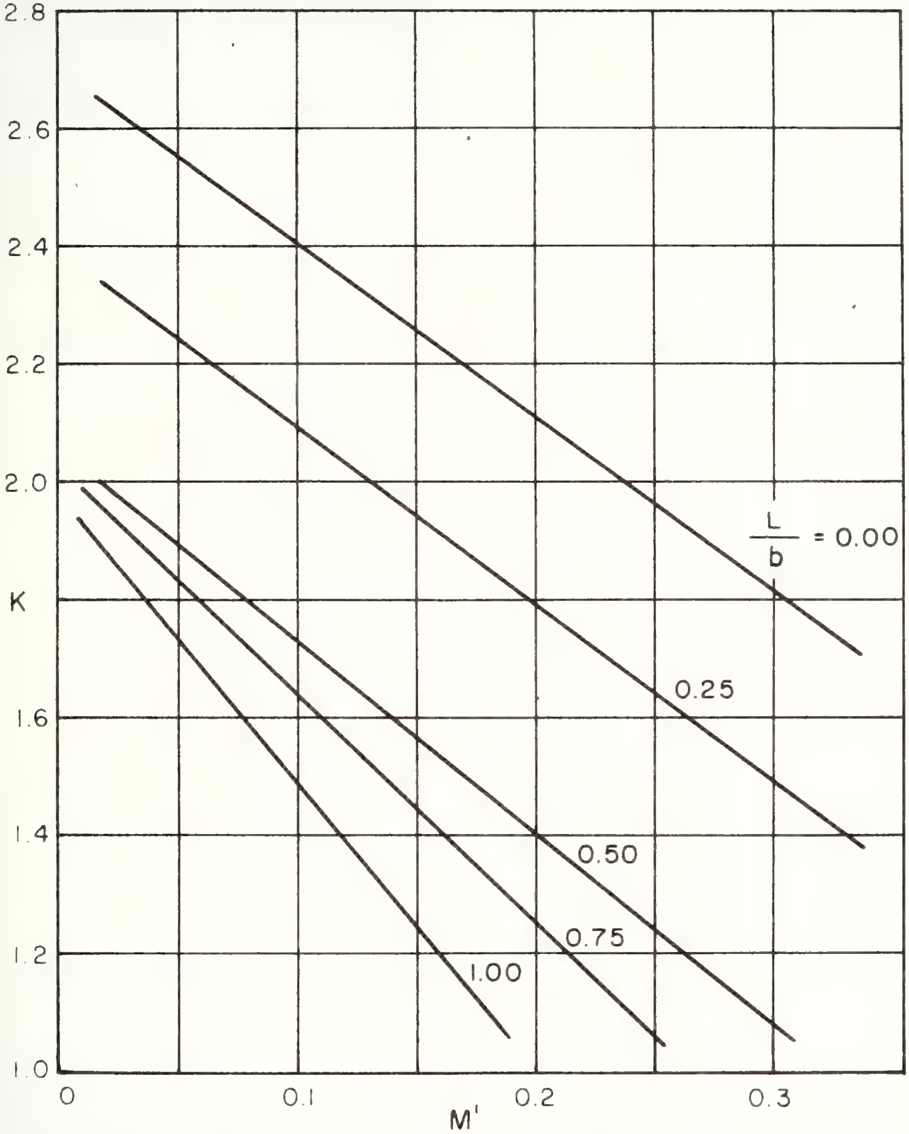


FIG. 8-9-6 SUMMARY OF HEAD LOSS COEFFICIENT CURVES FOR GEOMETRIES I_a, & I_b, SMOOTH BOUNDARIES

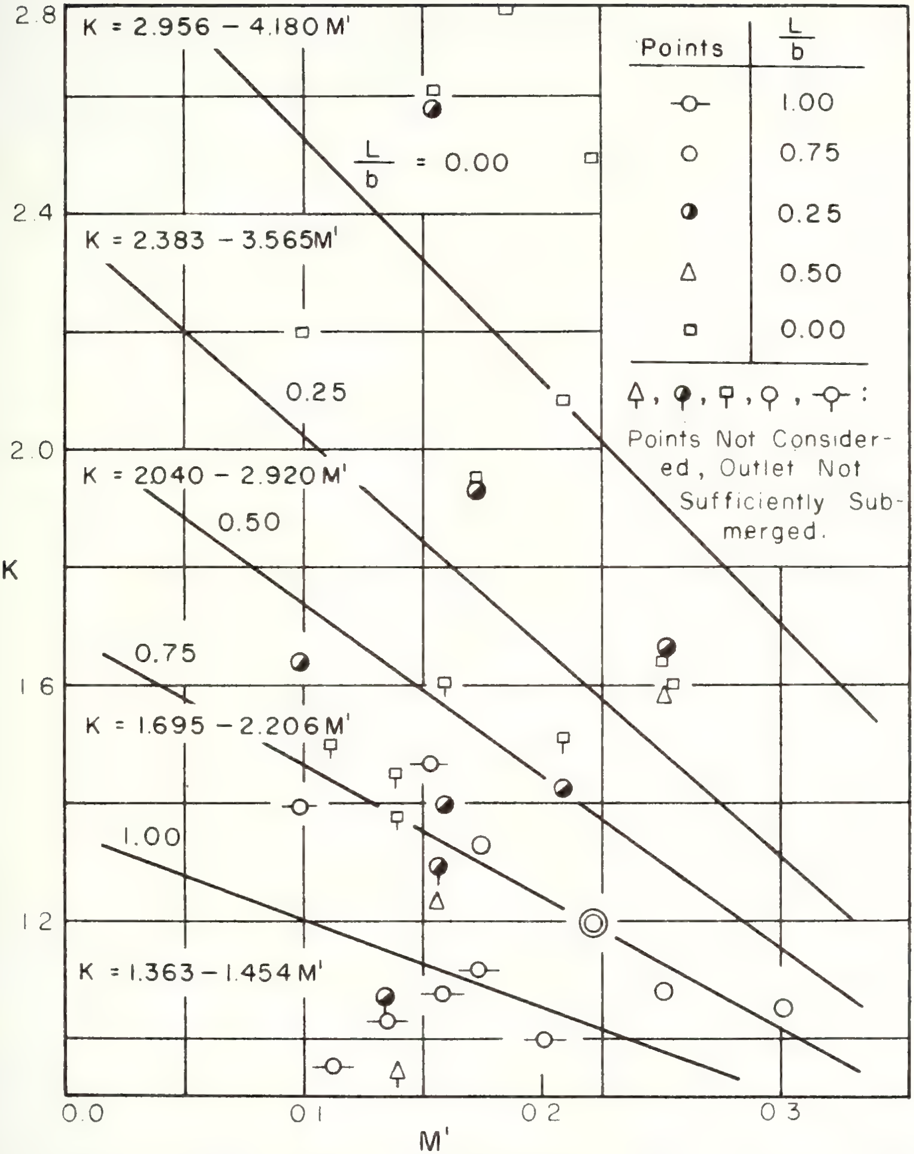


FIG. 8-9-7 HEAD LOSS COEFFICIENT CURVES FOR GEOMETRIES I_a, & I_b, ROUGH BOUNDARIES

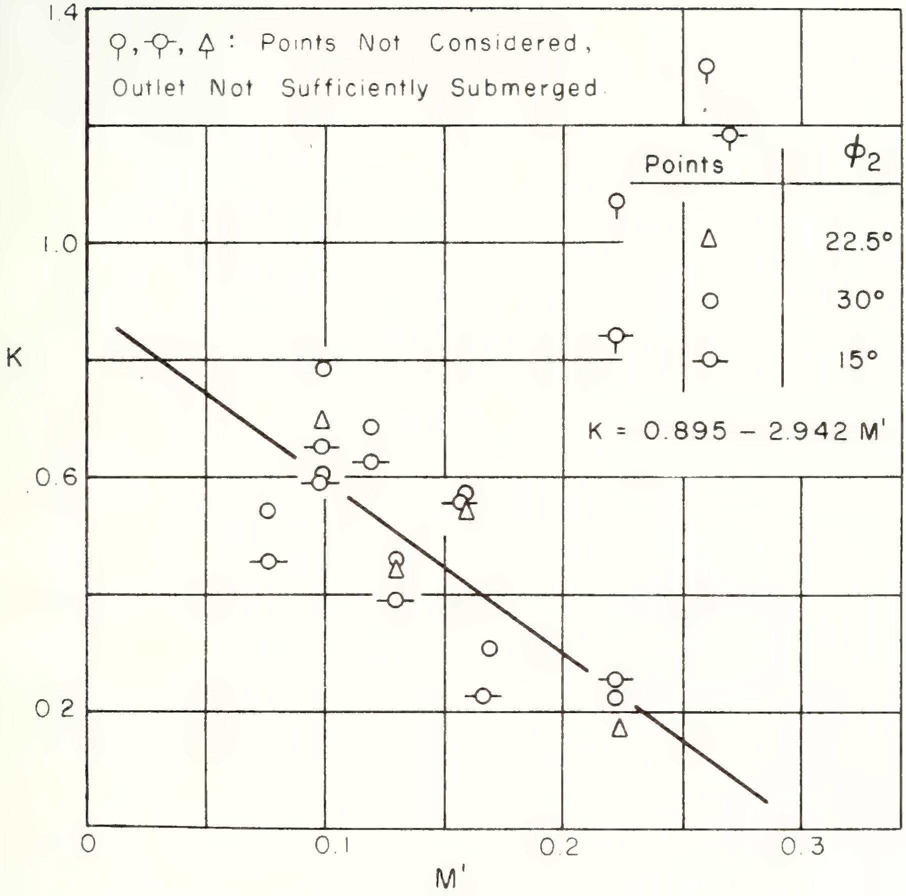


FIG. 8-9-8 HEAD LOSS COEFFICIENT CURVE FOR GEOMETRY V_b, ROUGH BOUNDARIES

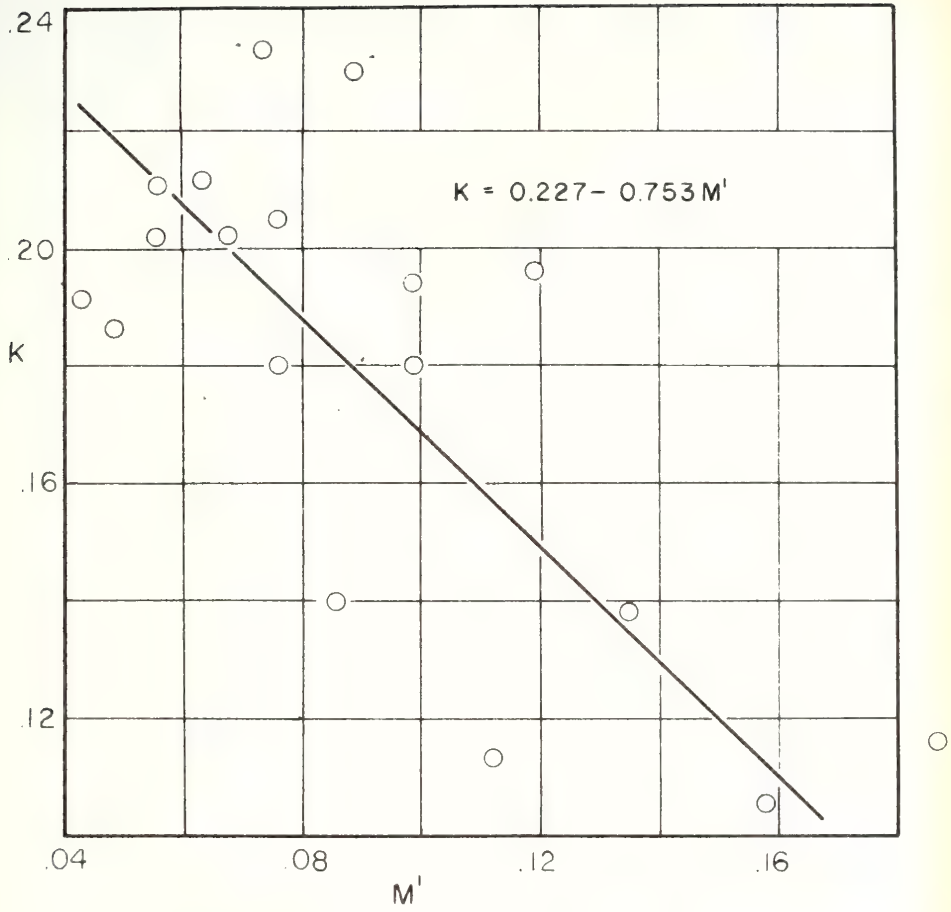


FIG. 8-9-9 HEAD LOSS COEFFICIENT CURVE FOR GEOMETRY VI, ROUGH BOUNDARIES

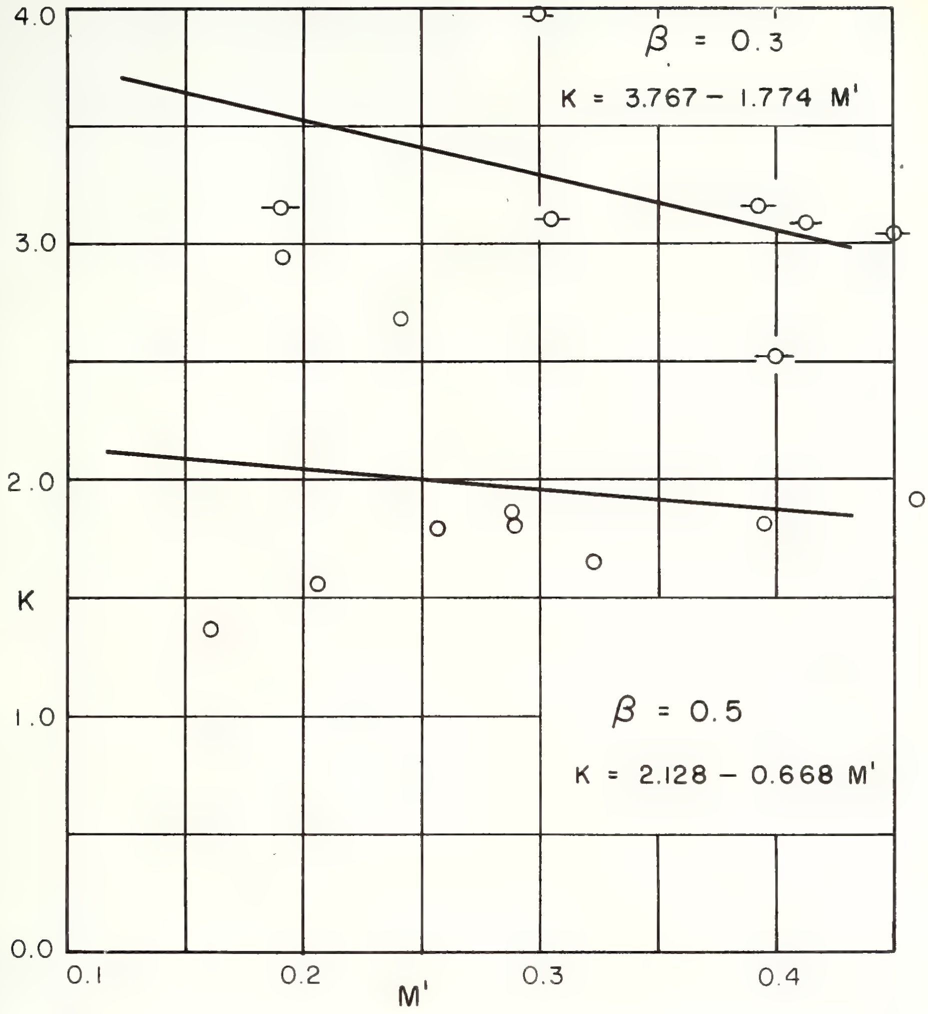


FIG. 8-9-10 HEAD LOSS COEFFICIENT CURVES FOR GEOMETRY VII, ROUGH BOUNDARIES

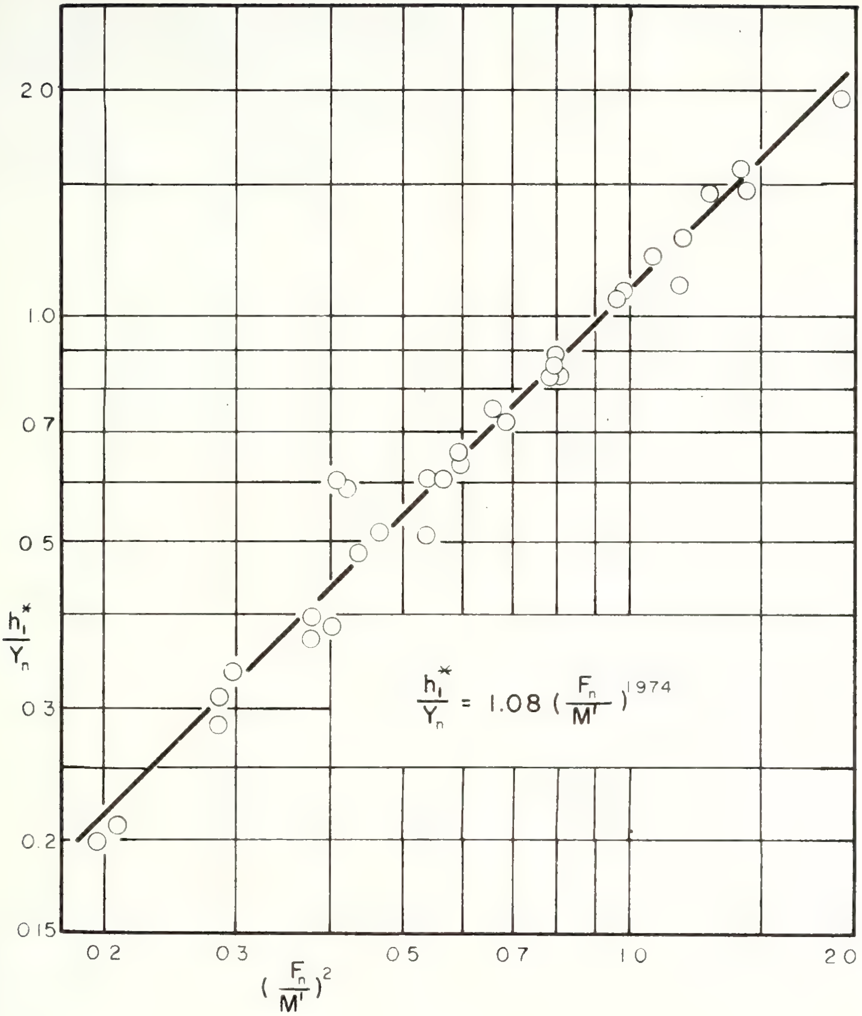


FIG. 8-10-I GENERALIZED BACKWATER RATIO GEOMETRY Ia, SMOOTH BOUNDARIES, $\frac{L}{b} = 0.0$

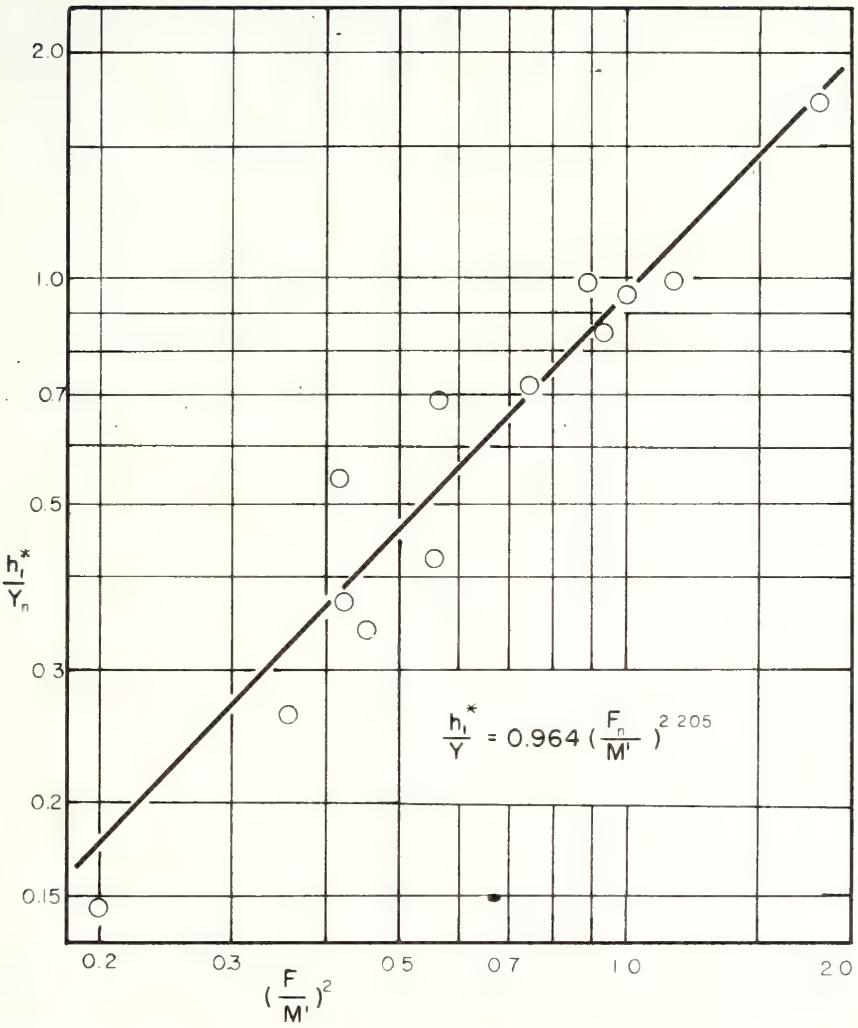


FIG.8-10-2GENERALIZED BACKWATER RATIO GEOMETRY Ib, SMOOTH BOUNDARIES, $\frac{L}{b} = 0.25$

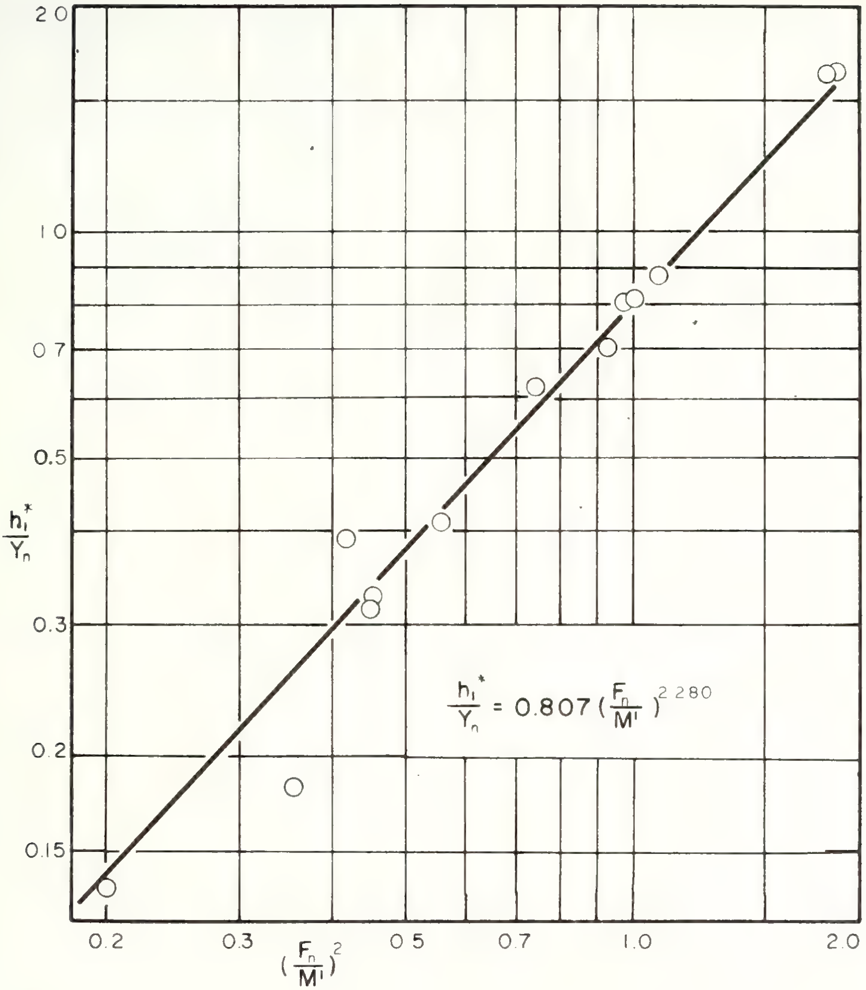


FIG. 8-10-3 GENERALIZED BACKWATER RATIO GEOMETRY Ib, SMOOTH BOUNDARIES, $\frac{L}{b} = 0.50$

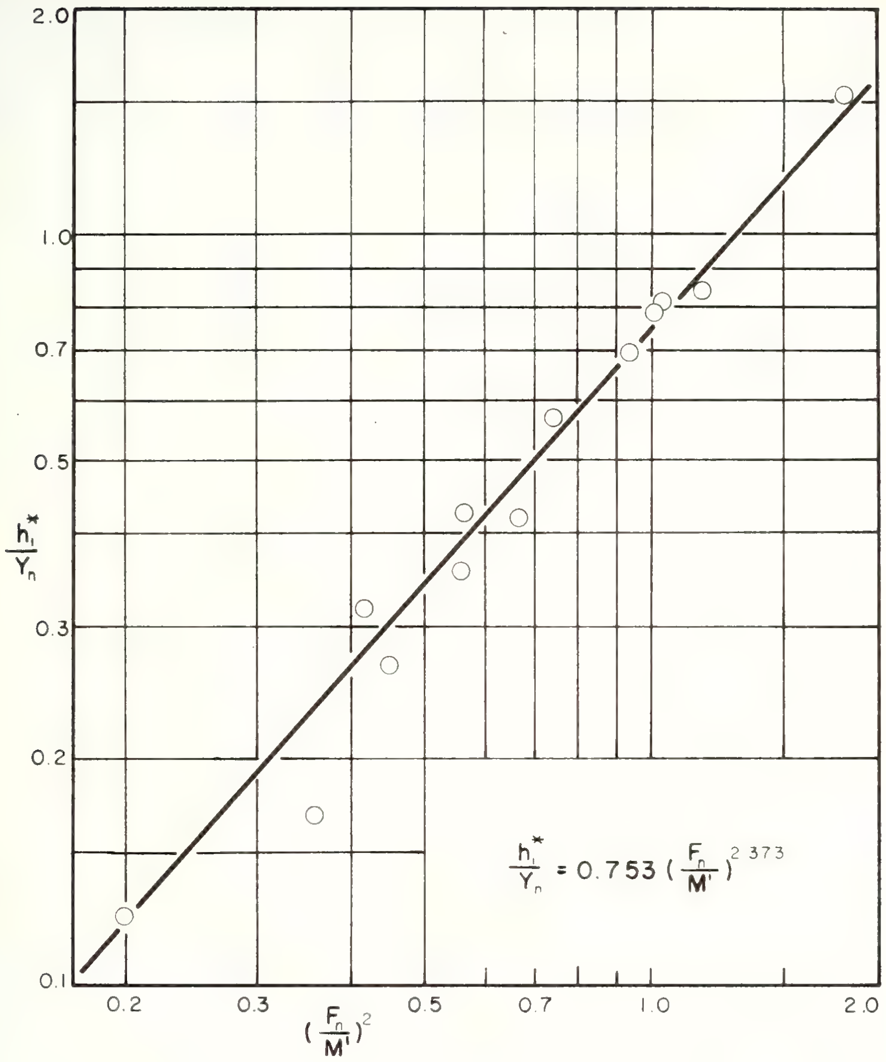


FIG. 8-10-4 GENERALIZED BACKWATER RATIO GEOMETRY Ib, SMOOTH BOUNDARIES, $\frac{L}{b} = 0.75$

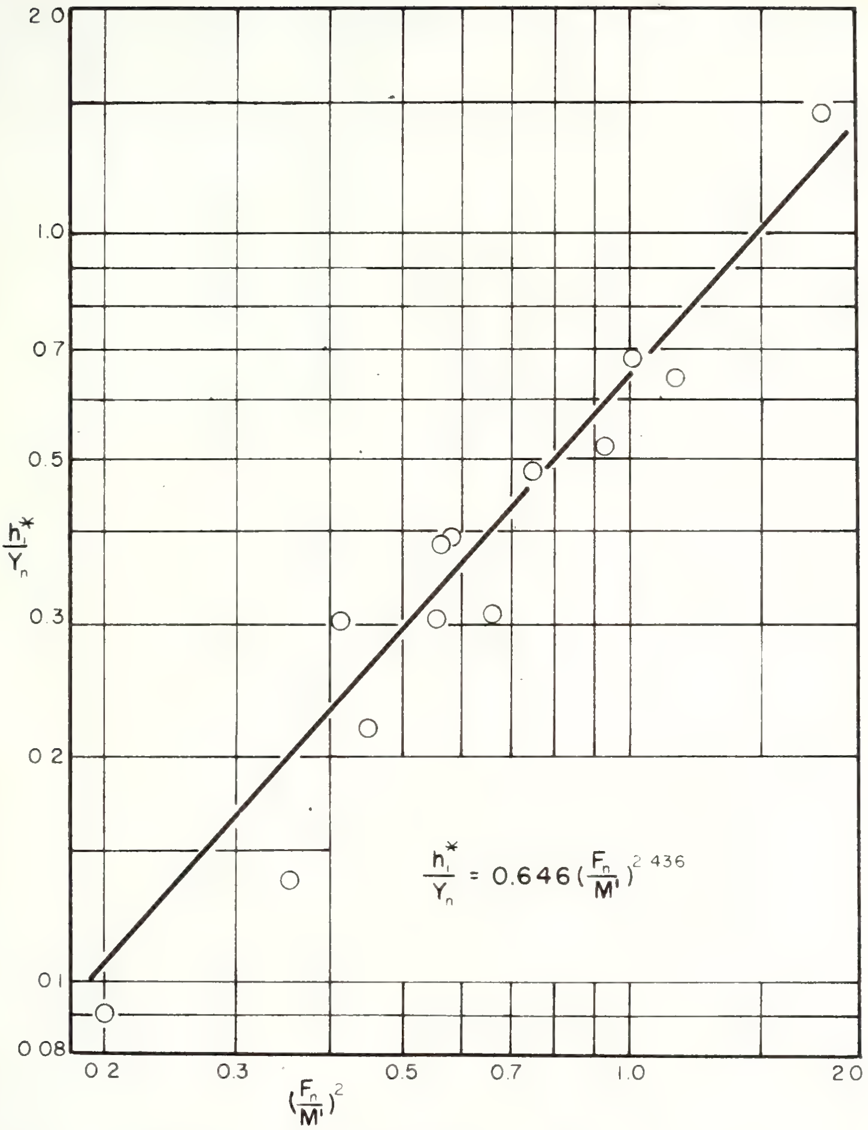


FIG. 8-10-5 GENERALIZED BACKWATER RATIO GEOMETRY Ib, SMOOTH BOUNDARIES, $\frac{L}{b} = 1.0$

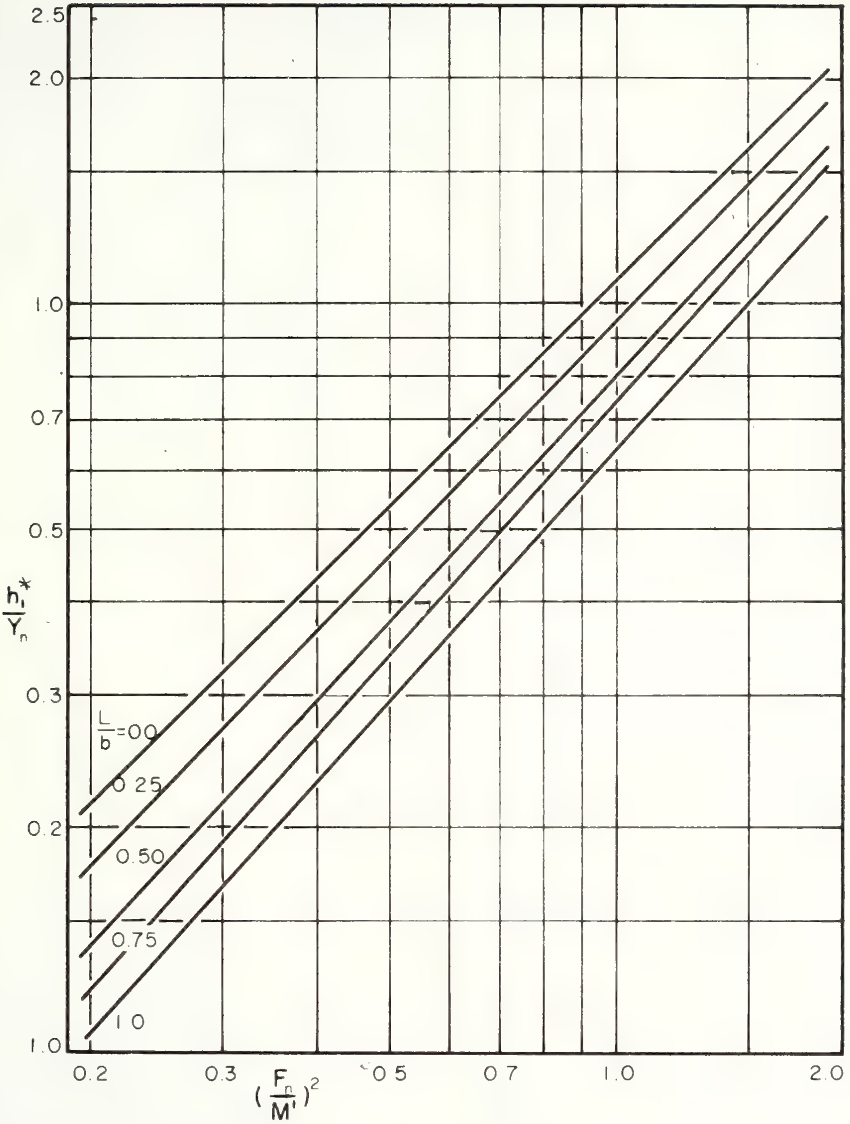


FIG. 8-10-6 SUMMARY OF BACKWATER RATIO CURVES FOR GEOMETRIES Ia AND Ib , SMOOTH BOUNDARIES

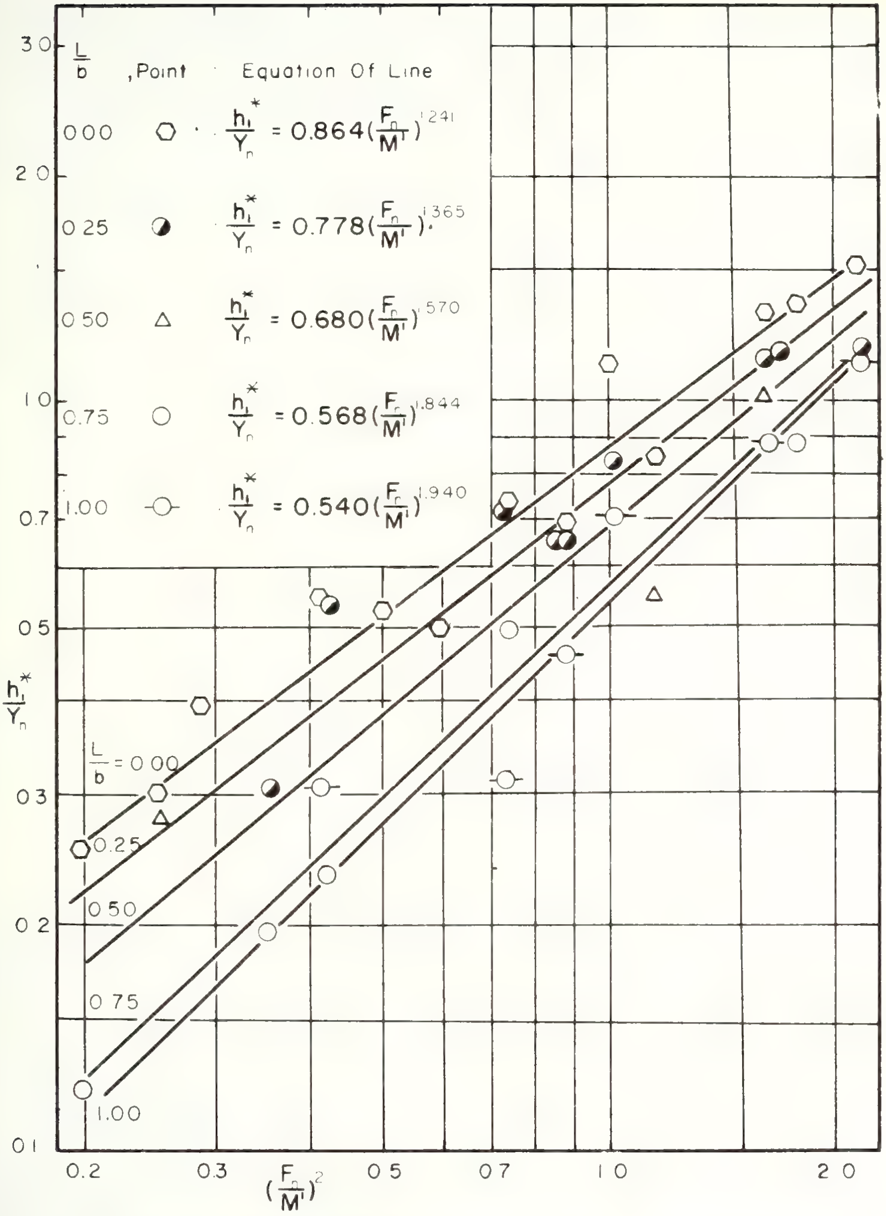


FIG. 8-10-7 GENERALIZED BACKWATER RATIO GEOMETRIES Ia AND Ib, ROUGH BOUNDARIES

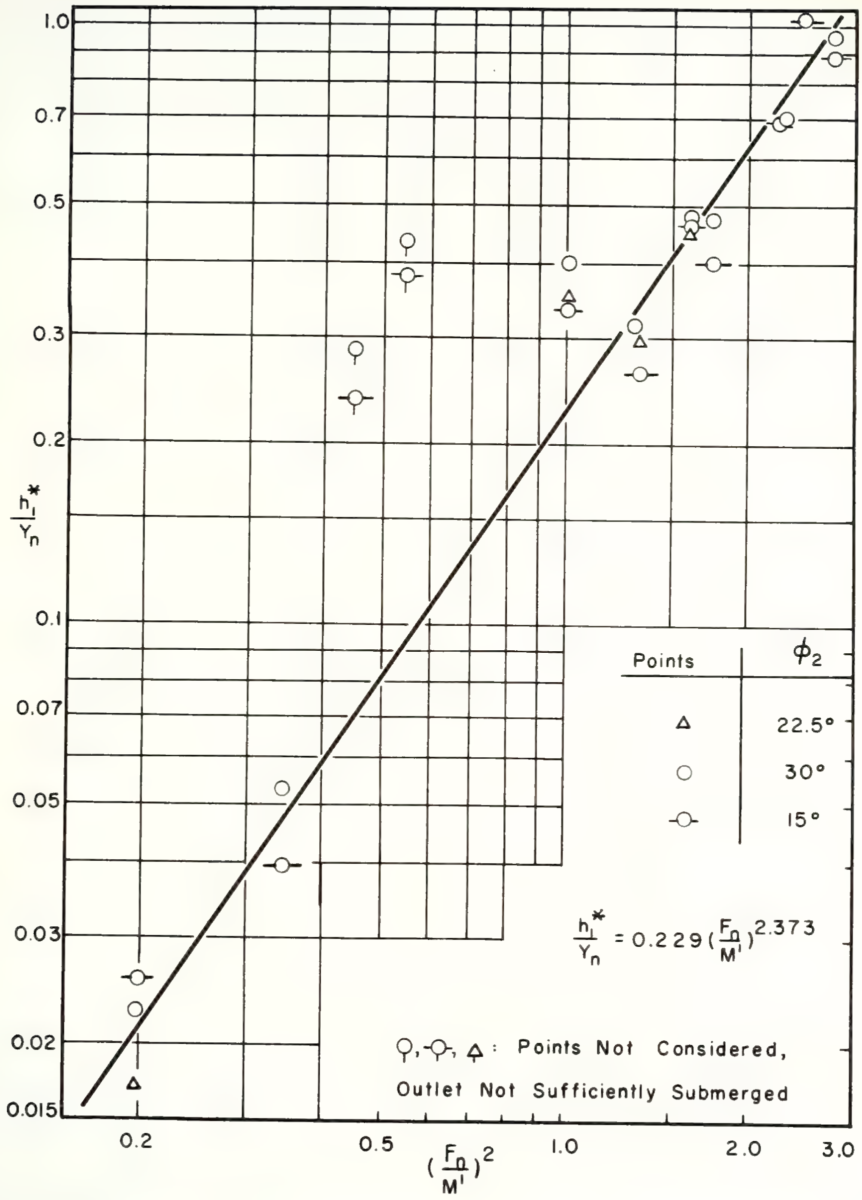


FIG. 8-10-8 GENERALIZED BACKWATER RATIO GEOMETRY Vb, ROUGH BOUNDARIES

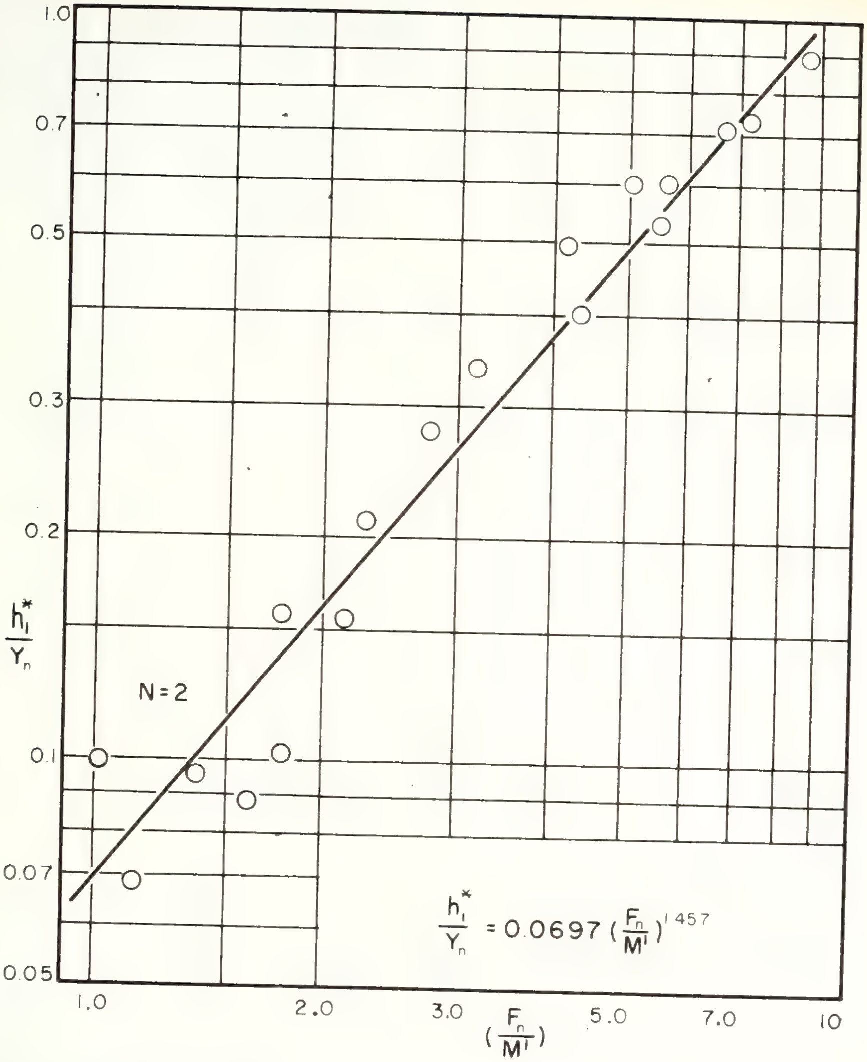


FIG. 8-10-9 GENERALIZED BACKWATER RATIO GEOMETRY VI, ROUGH BOUNDARIES

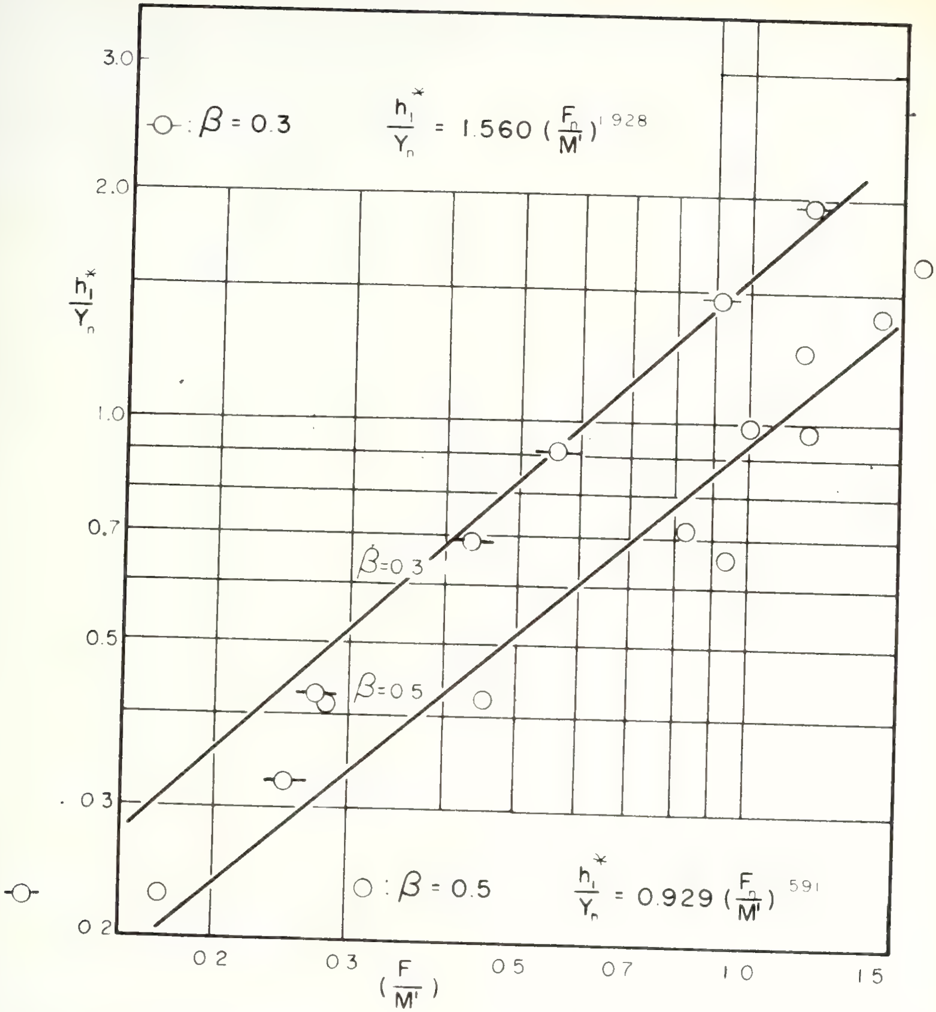


FIG. 8-10-10 GENERALIZED BACKWATER RATIO GEOMETRY VII, ROUGH BOUNDARIES

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION

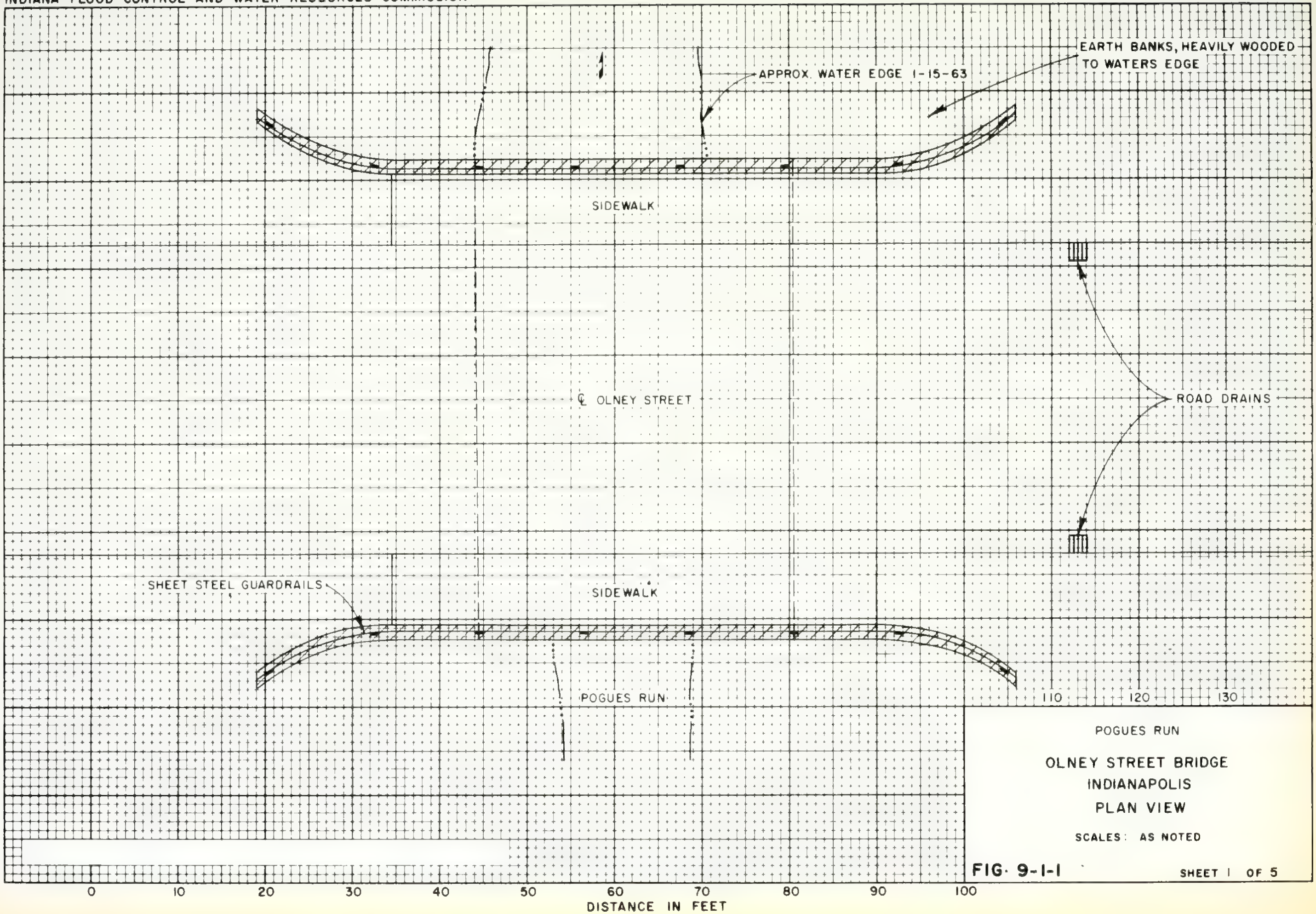
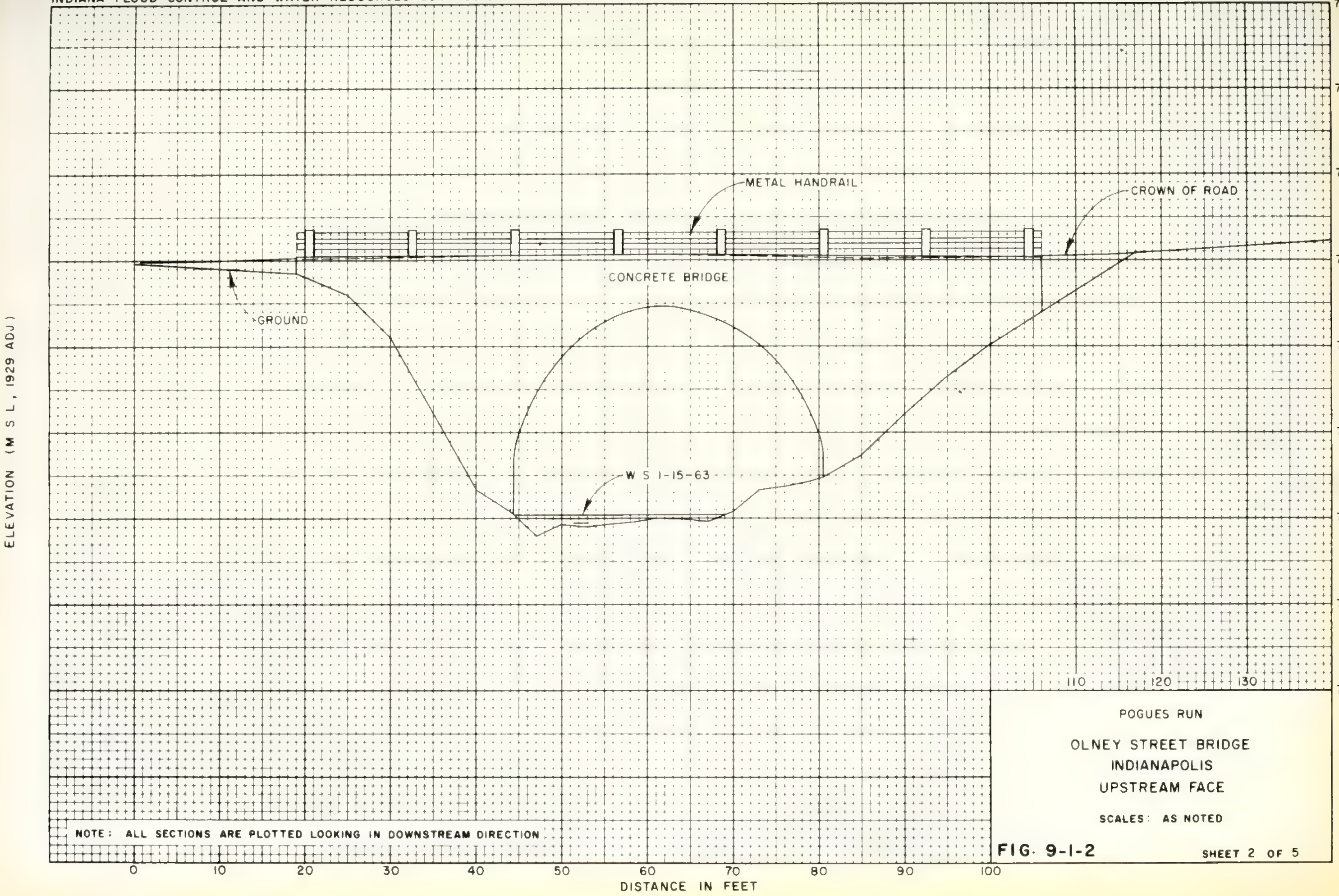


FIG. 9-1-1

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



NOTE: ALL SECTIONS ARE PLOTTED LOOKING IN DOWNSTREAM DIRECTION

POGUES RUN

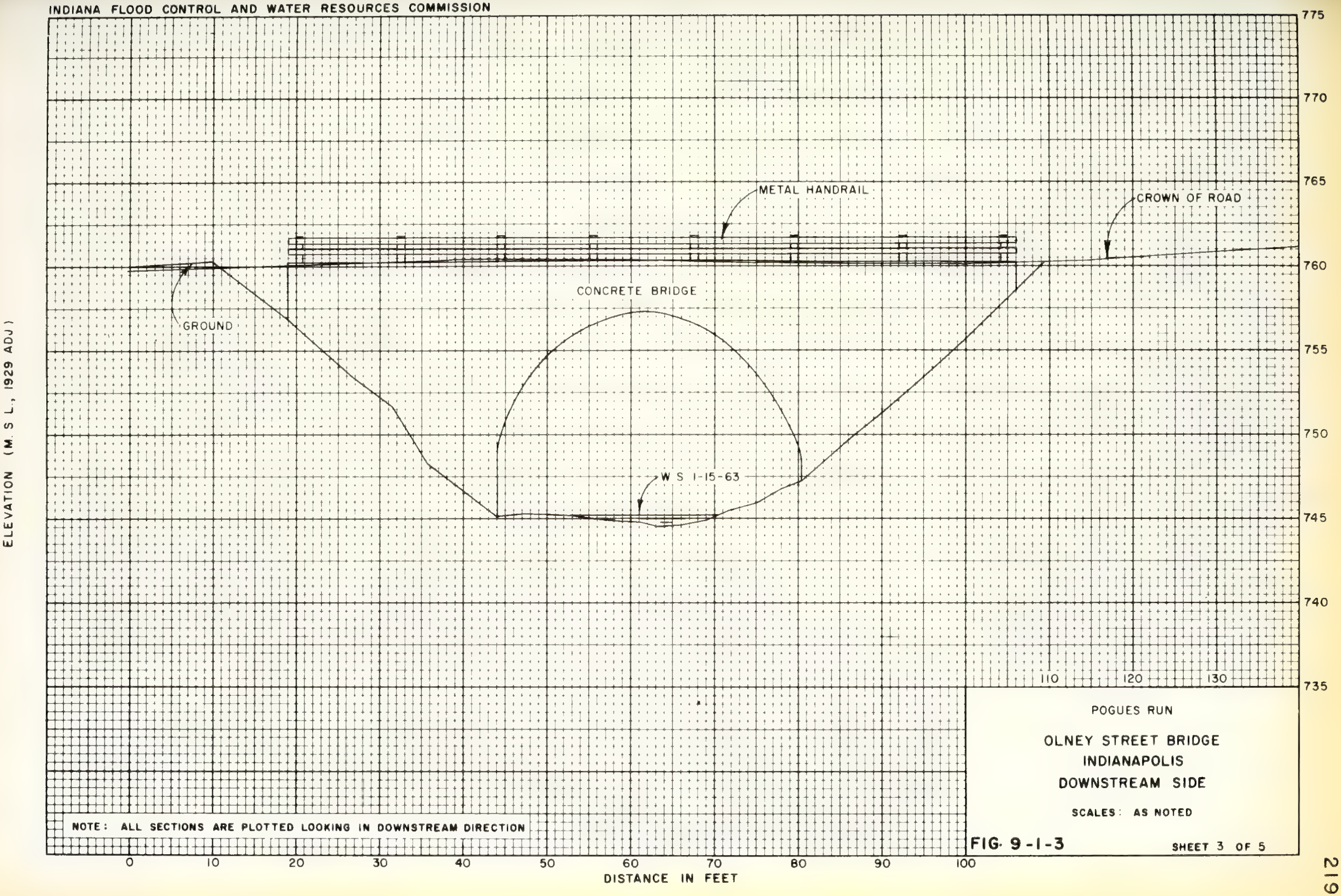
OLNEY STREET BRIDGE
INDIANAPOLIS
UPSTREAM FACE

SCALES: AS NOTED

FIG. 9-1-2

SHEET 2 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



NOTE: ALL SECTIONS ARE PLOTTED LOOKING IN DOWNSTREAM DIRECTION

POGUES RUN

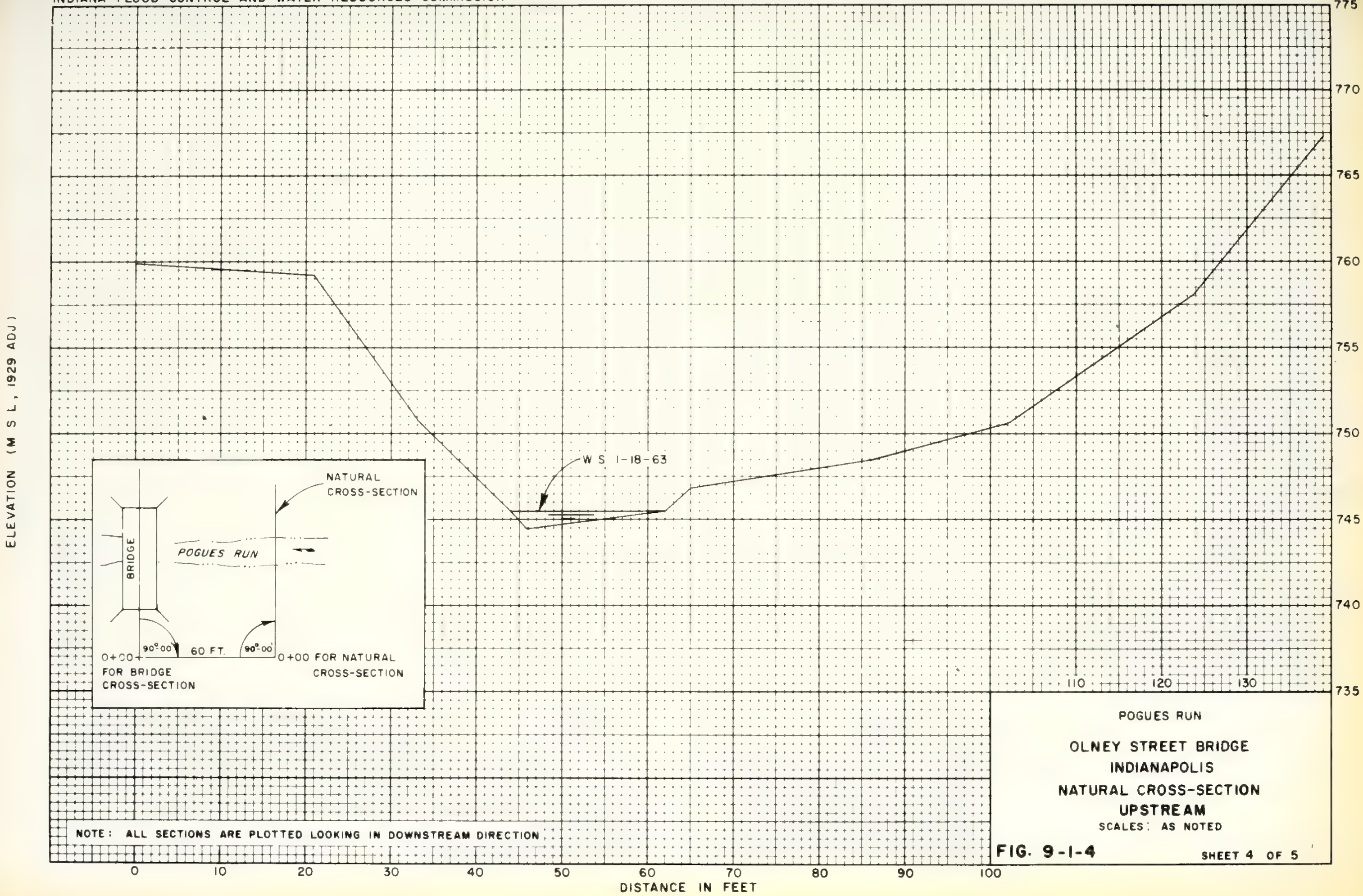
OLNEY STREET BRIDGE
INDIANAPOLIS
DOWNSTREAM SIDE

SCALES: AS NOTED

FIG. 9-1-3

SHEET 3 OF 5

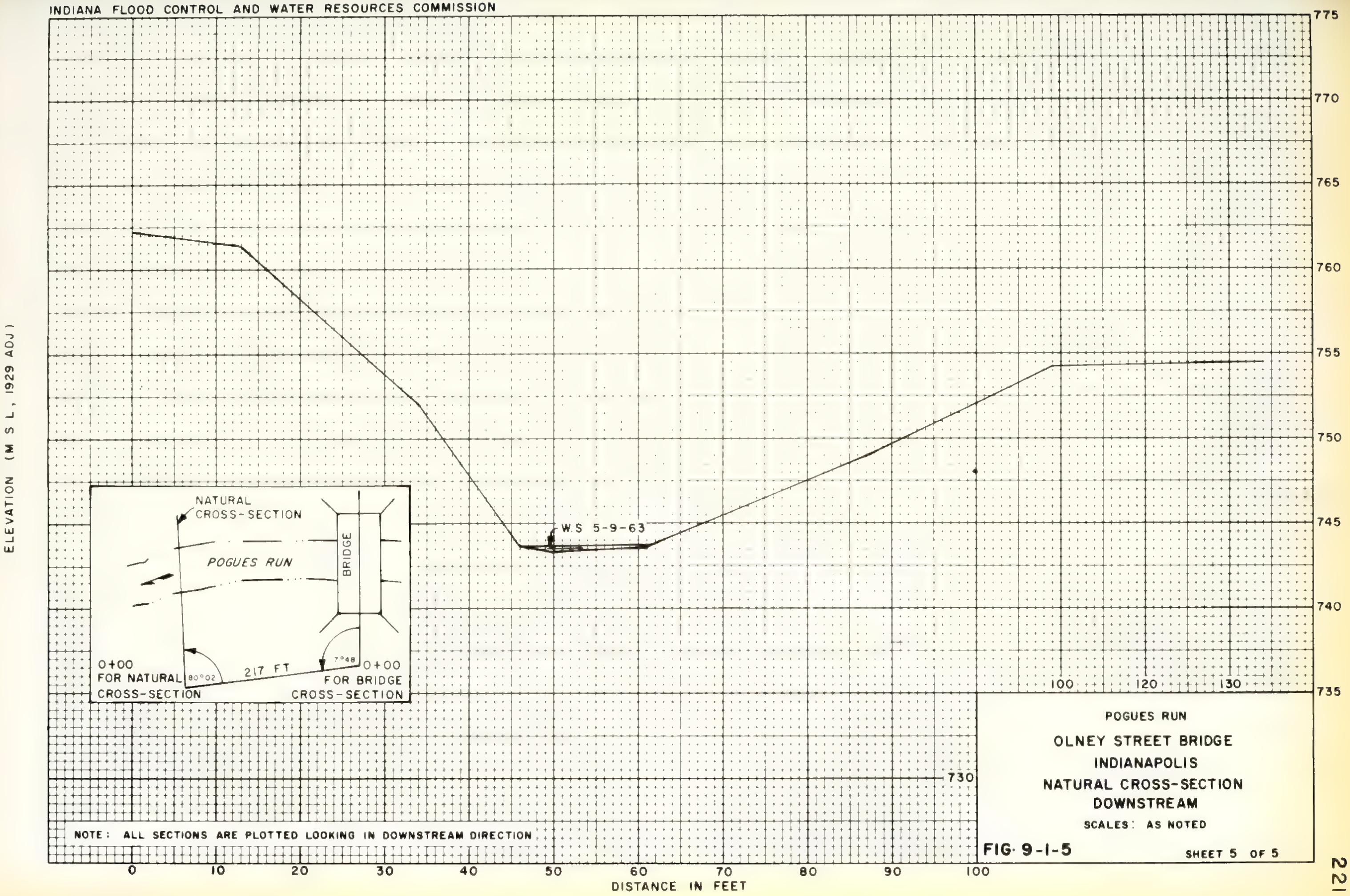
INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



POGUES RUN

OLNEY STREET BRIDGE
INDIANAPOLIS
NATURAL CROSS-SECTION
UPSTREAM
SCALES: AS NOTED

FIG. 9-1-4 SHEET 4 OF 5



POGUES RUN

OLNEY STREET BRIDGE

INDIANAPOLIS

NATURAL CROSS-SECTION

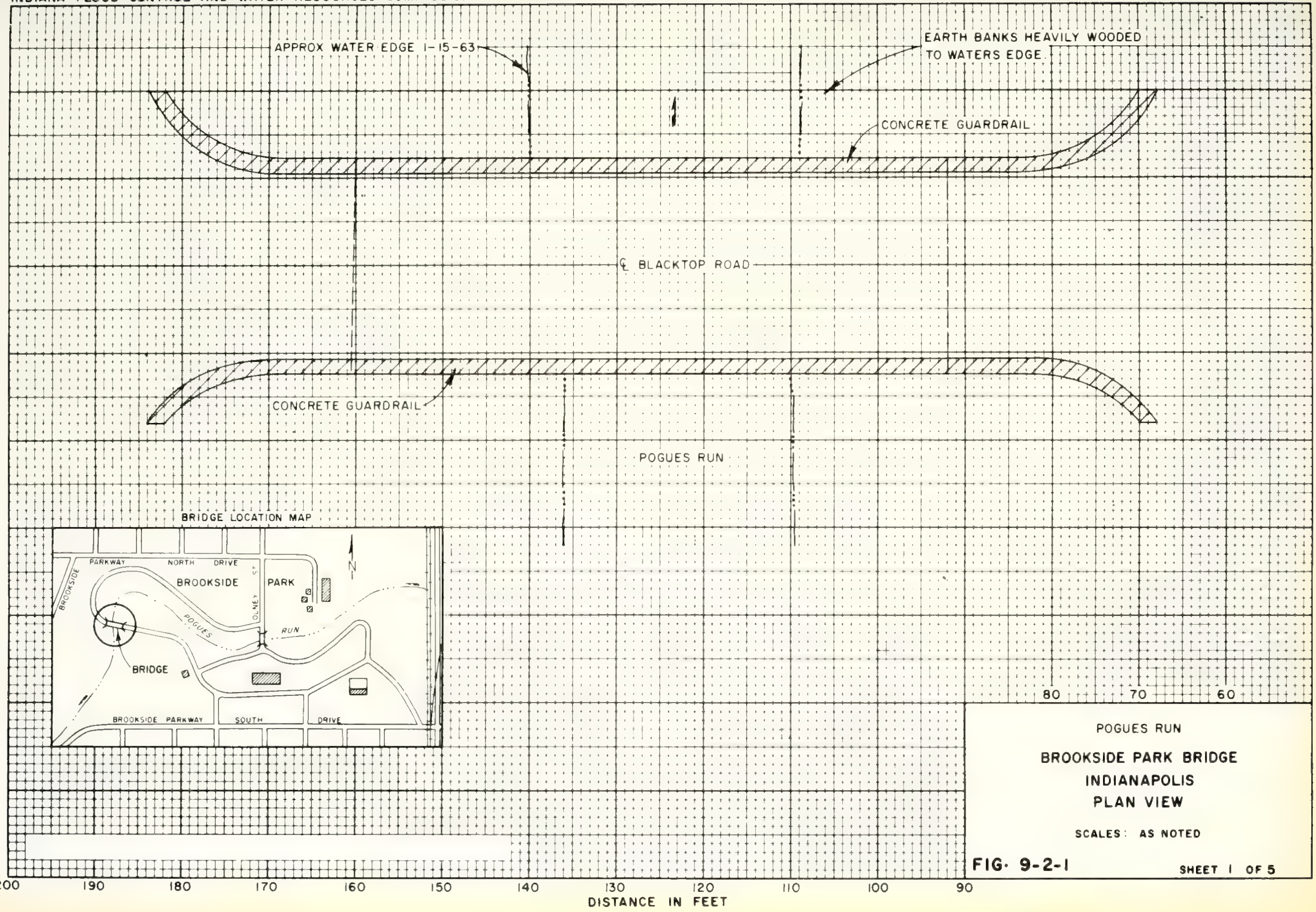
DOWNSTREAM

SCALES: AS NOTED

FIG. 9-1-5

SHEET 5 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



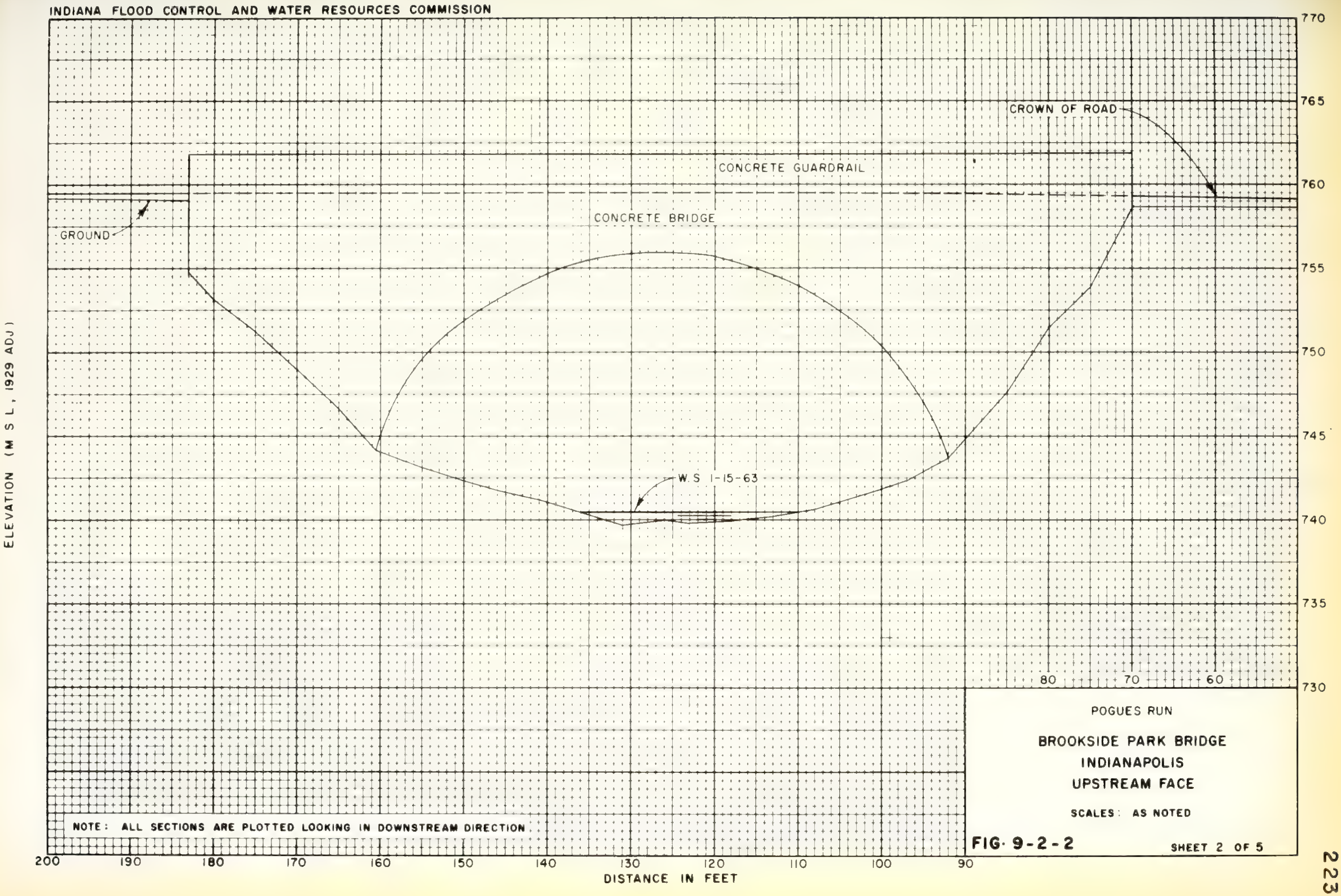
POGUES RUN

BROOKSIDE PARK BRIDGE
INDIANAPOLIS
PLAN VIEW

SCALES: AS NOTED

FIG. 9-2-1

SHEET 1 OF 5


INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION
ELEVATION (M S L, 1929 ADJ)
770
765
760
755
750
745
740
735
730
CROWN OF ROAD
CONCRETE GUARDRAIL
CONCRETE BRIDGE
GROUND
W.S 1-15-63
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
DISTANCE IN FEET
NOTE: ALL SECTIONS ARE PLOTTED LOOKING IN DOWNSTREAM DIRECTION
POGUES RUN
BROOKSIDE PARK BRIDGE
INDIANAPOLIS
UPSTREAM FACE
SCALES: AS NOTED
FIG. 9-2-2
SHEET 2 OF 5

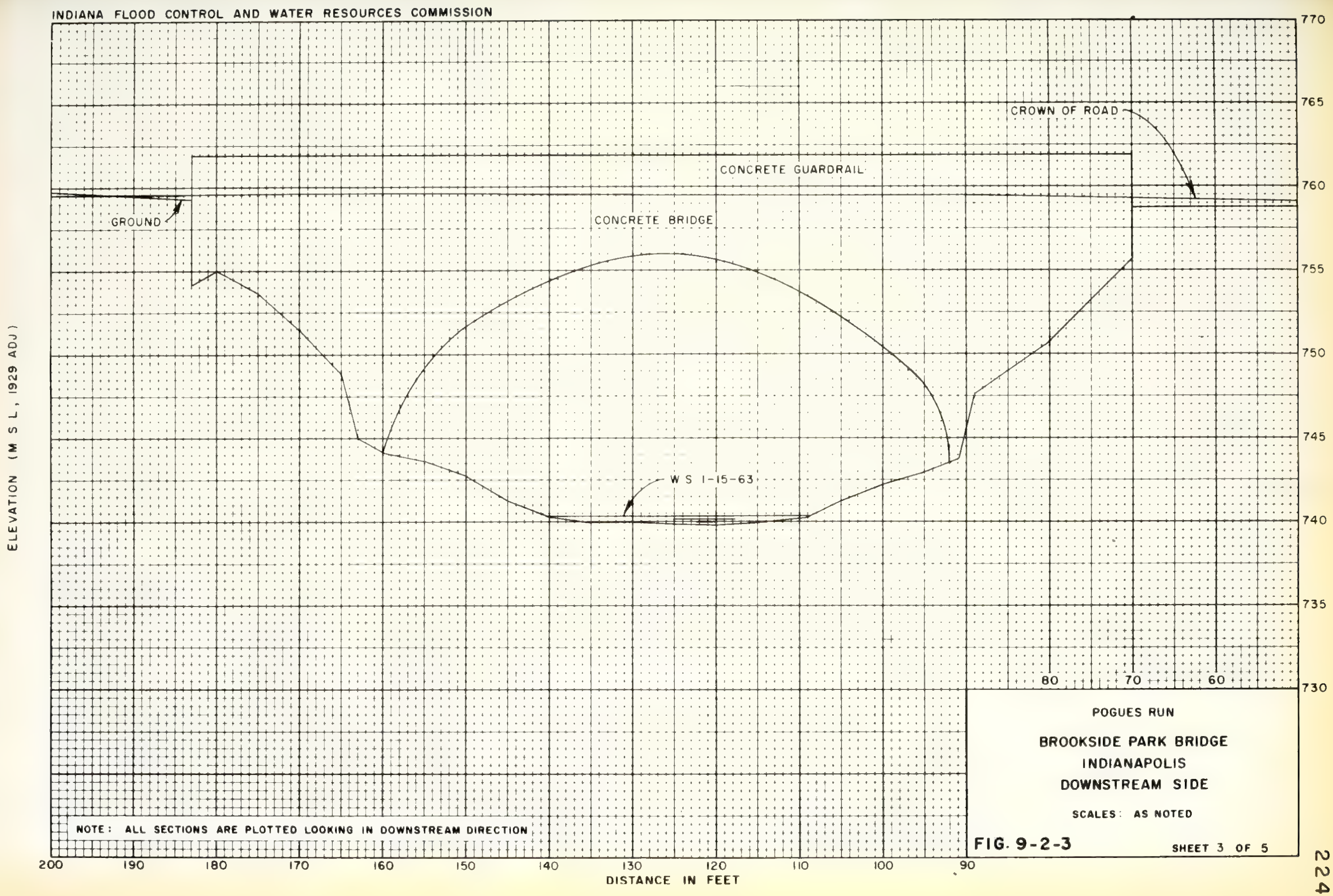
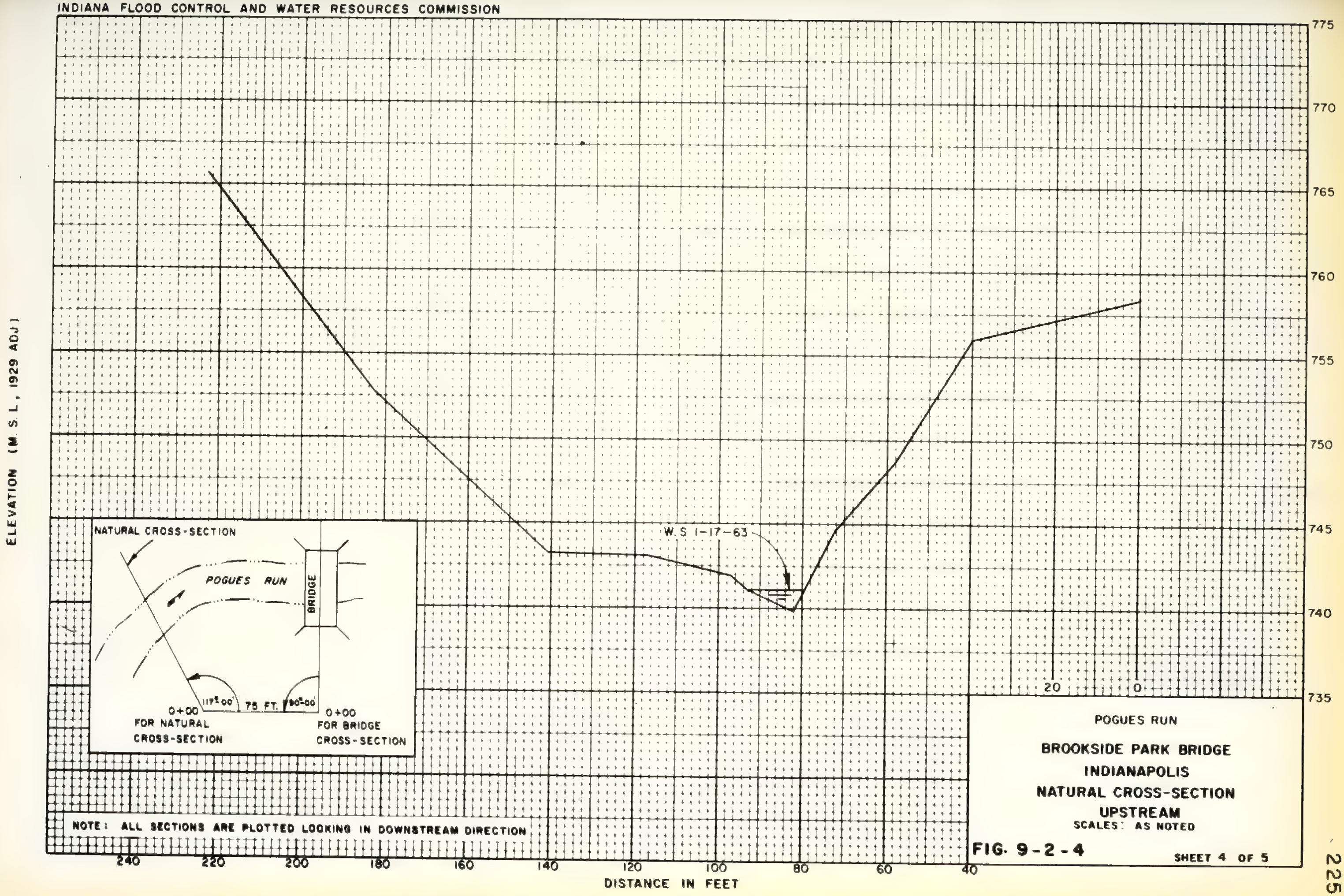

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION
CROWN OF ROAD
CONCRETE GUARDRAIL
GROUND
CONCRETE BRIDGE
W S 1-15-63
ELEVATION (M S L, 1929 ADJ)
770
765
760
755
750
745
740
735
730
DISTANCE IN FEET
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
NOTE: ALL SECTIONS ARE PLOTTED LOOKING IN DOWNSTREAM DIRECTION
POGUES RUN
BROOKSIDE PARK BRIDGE
INDIANAPOLIS
DOWNSTREAM SIDE
SCALES: AS NOTED
SHEET 3 OF 5

FIG. 9-2-3

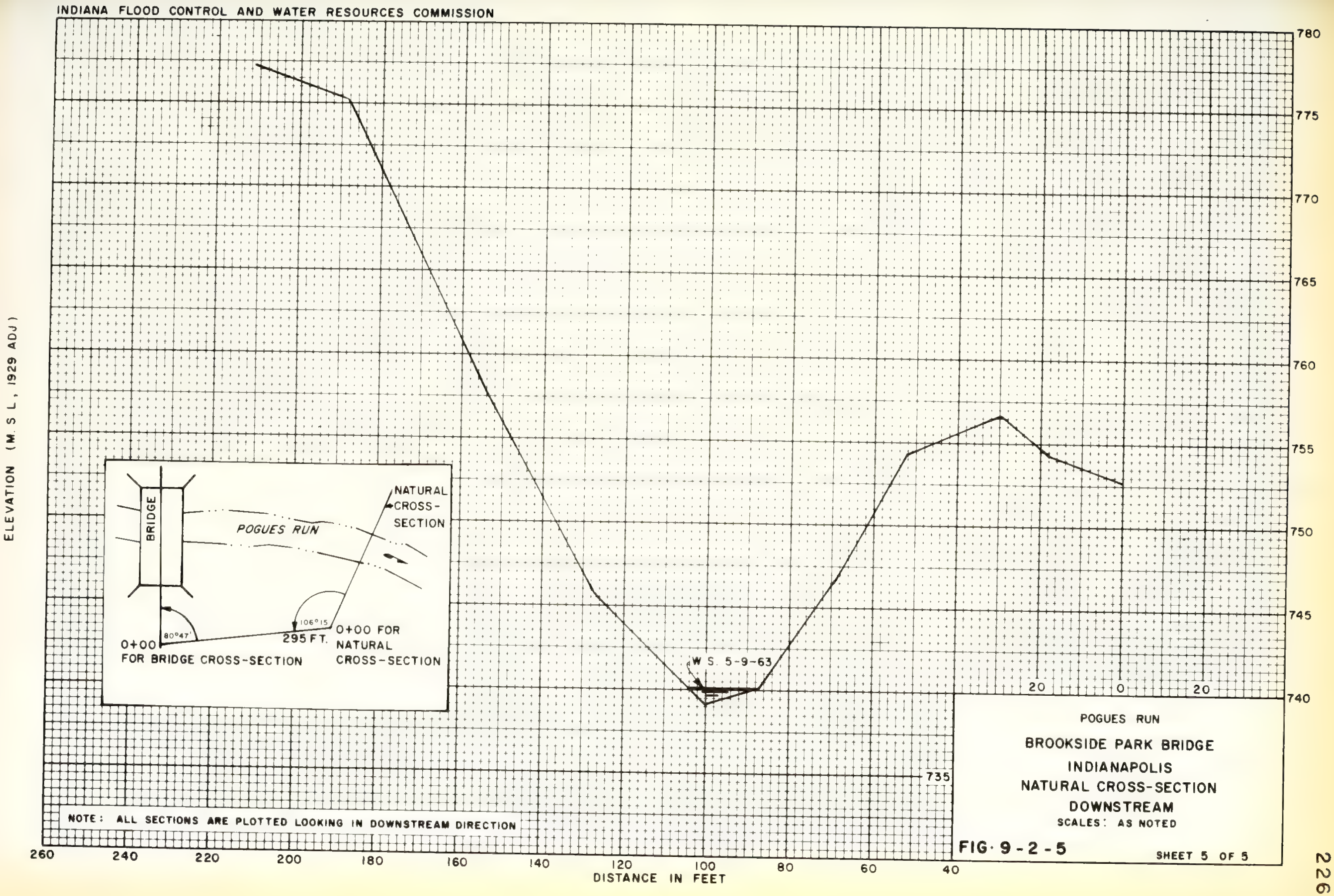


POGUES RUN

BROOKSIDE PARK BRIDGE
INDIANAPOLIS
NATURAL CROSS-SECTION
UPSTREAM
SCALES: AS NOTED

FIG. 9-2-4

SHEET 4 OF 5



POGUES RUN

BROOKSIDE PARK BRIDGE

INDIANAPOLIS

NATURAL CROSS-SECTION

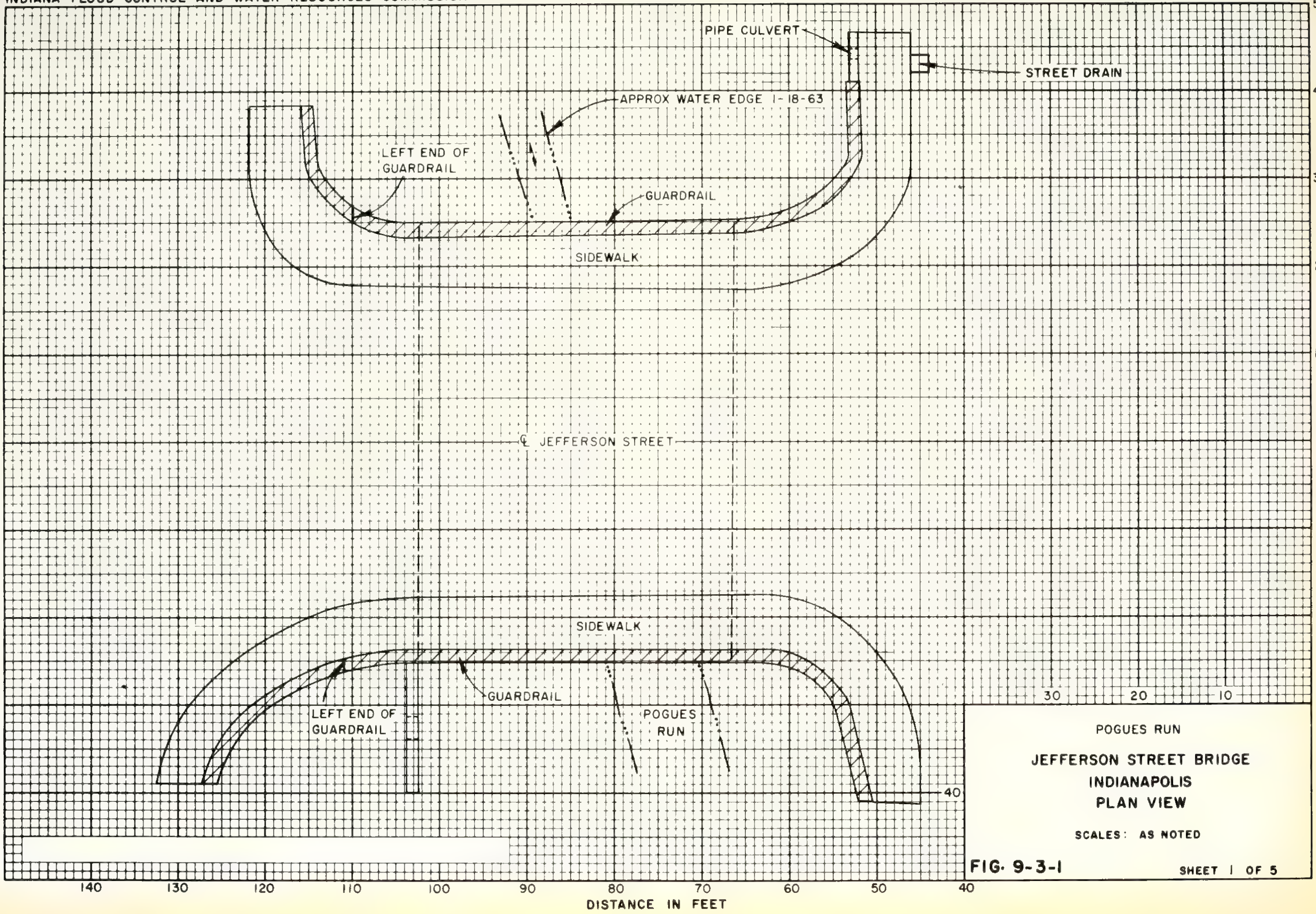
DOWNSTREAM

SCALES: AS NOTED

FIG. 9-2-5

SHEET 5 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



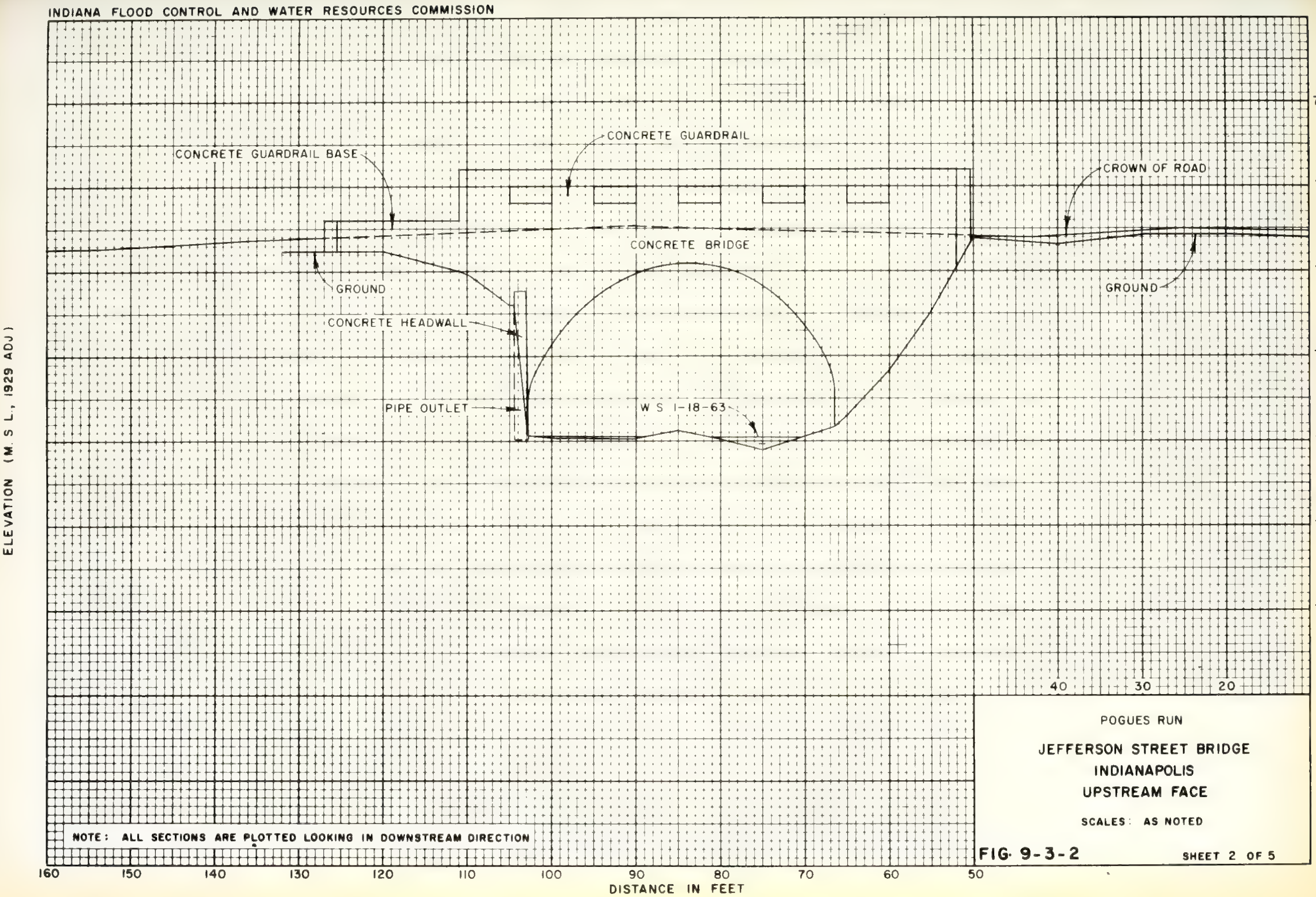
POGUES RUN

JEFFERSON STREET BRIDGE
INDIANAPOLIS
PLAN VIEW

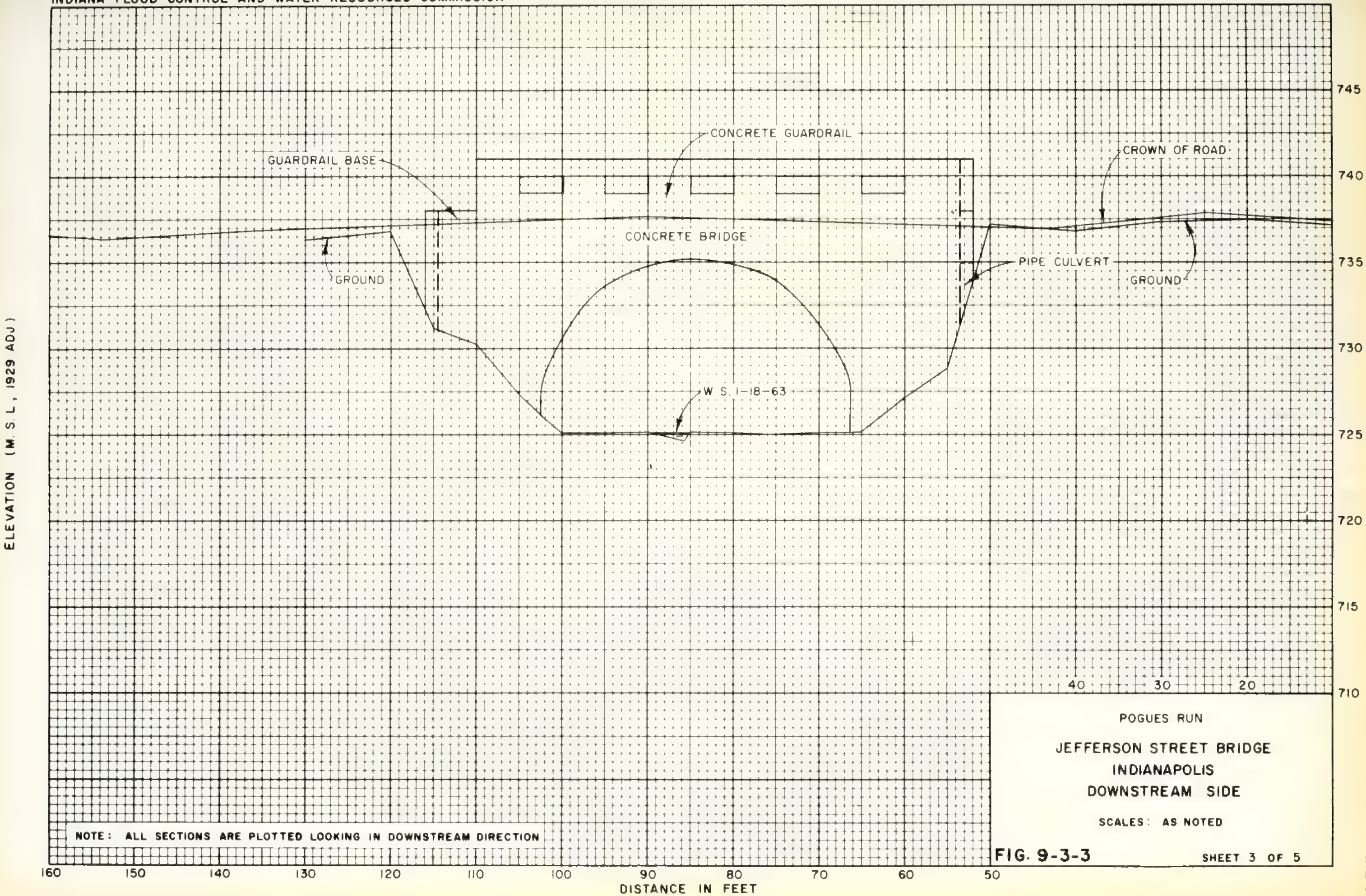
SCALES: AS NOTED

FIG. 9-3-1

SHEET 1 OF 5


INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION
CONCRETE GUARDRAIL
CONCRETE GUARDRAIL BASE
CROWN OF ROAD
CONCRETE BRIDGE
GROUND
GROUND
CONCRETE HEADWALL
PIPE OUTLET
W S 1-18-63
745
740
735
730
725
720
715
710
ELEVATION (M. S. L., 1929 ADJ)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
DISTANCE IN FEET
NOTE: ALL SECTIONS ARE PLOTTED LOOKING IN DOWNSTREAM DIRECTION
POGUES RUN
JEFFERSON STREET BRIDGE
INDIANAPOLIS
UPSTREAM FACE
SCALES: AS NOTED
FIG. 9-3-2
SHEET 2 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



POGUES RUN

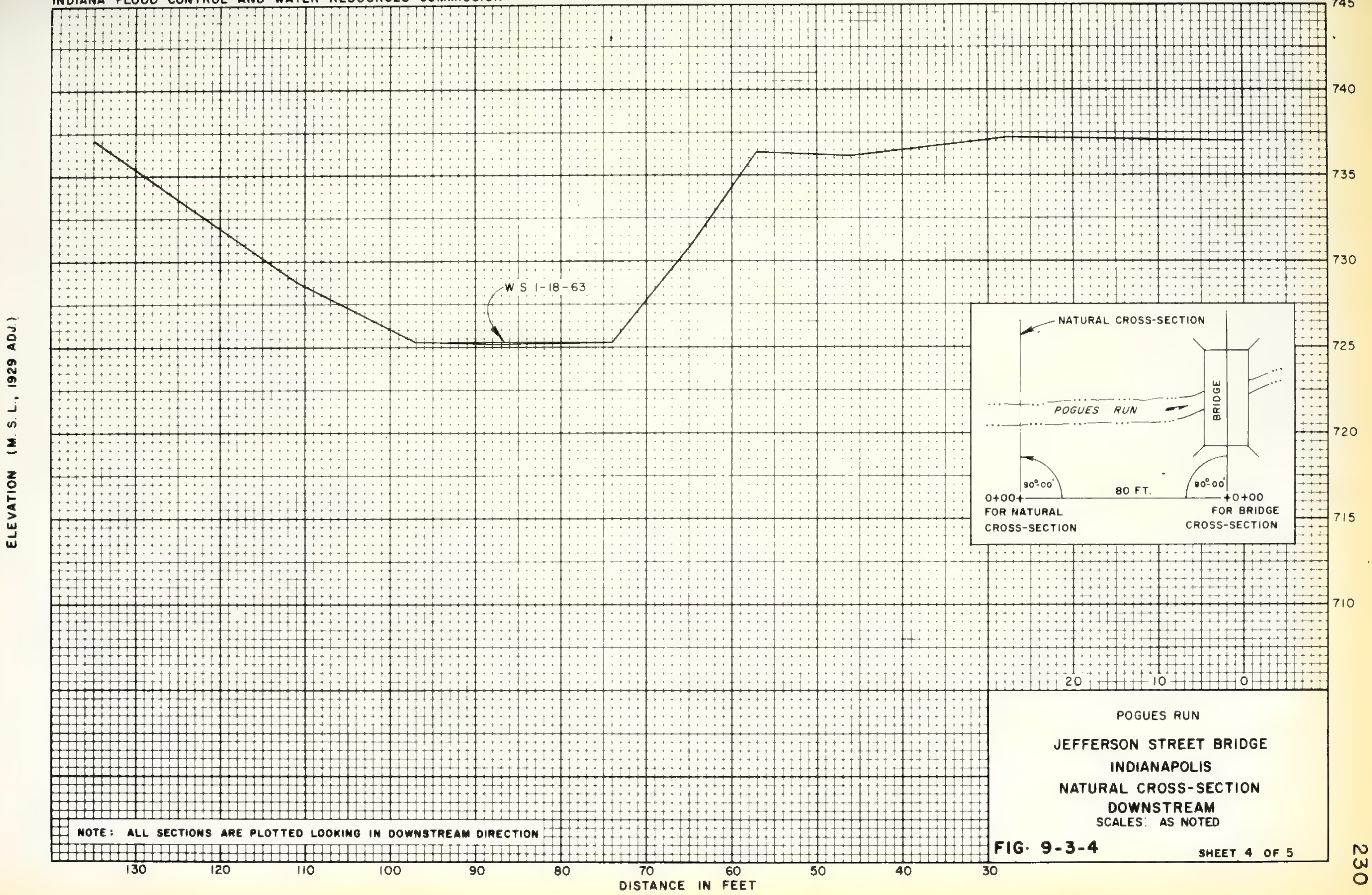
JEFFERSON STREET BRIDGE
INDIANAPOLIS
DOWNSTREAM SIDE

SCALES: AS NOTED

FIG. 9-3-3

SHEET 3 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



NOTE: ALL SECTIONS ARE PLOTTED LOOKING IN DOWNSTREAM DIRECTION

POGUES RUN

JEFFERSON STREET BRIDGE

INDIANAPOLIS

NATURAL CROSS-SECTION

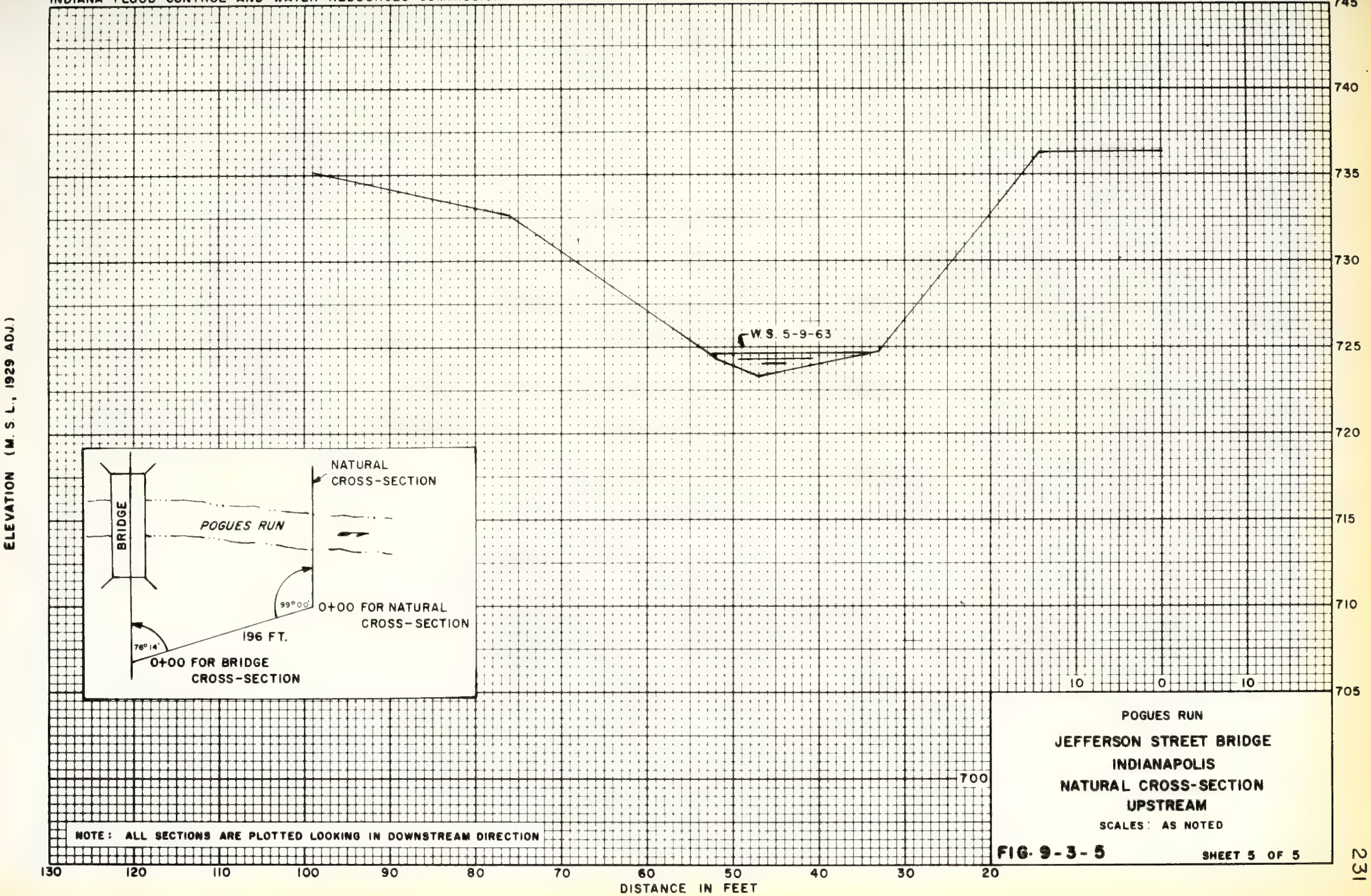
DOWNSTREAM

SCALES: AS NOTED

FIG. 9-3-4

SHEET 4 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



NOTE: ALL SECTIONS ARE PLOTTED LOOKING IN DOWNSTREAM DIRECTION

POGUES RUN

JEFFERSON STREET BRIDGE

INDIANAPOLIS

NATURAL CROSS-SECTION

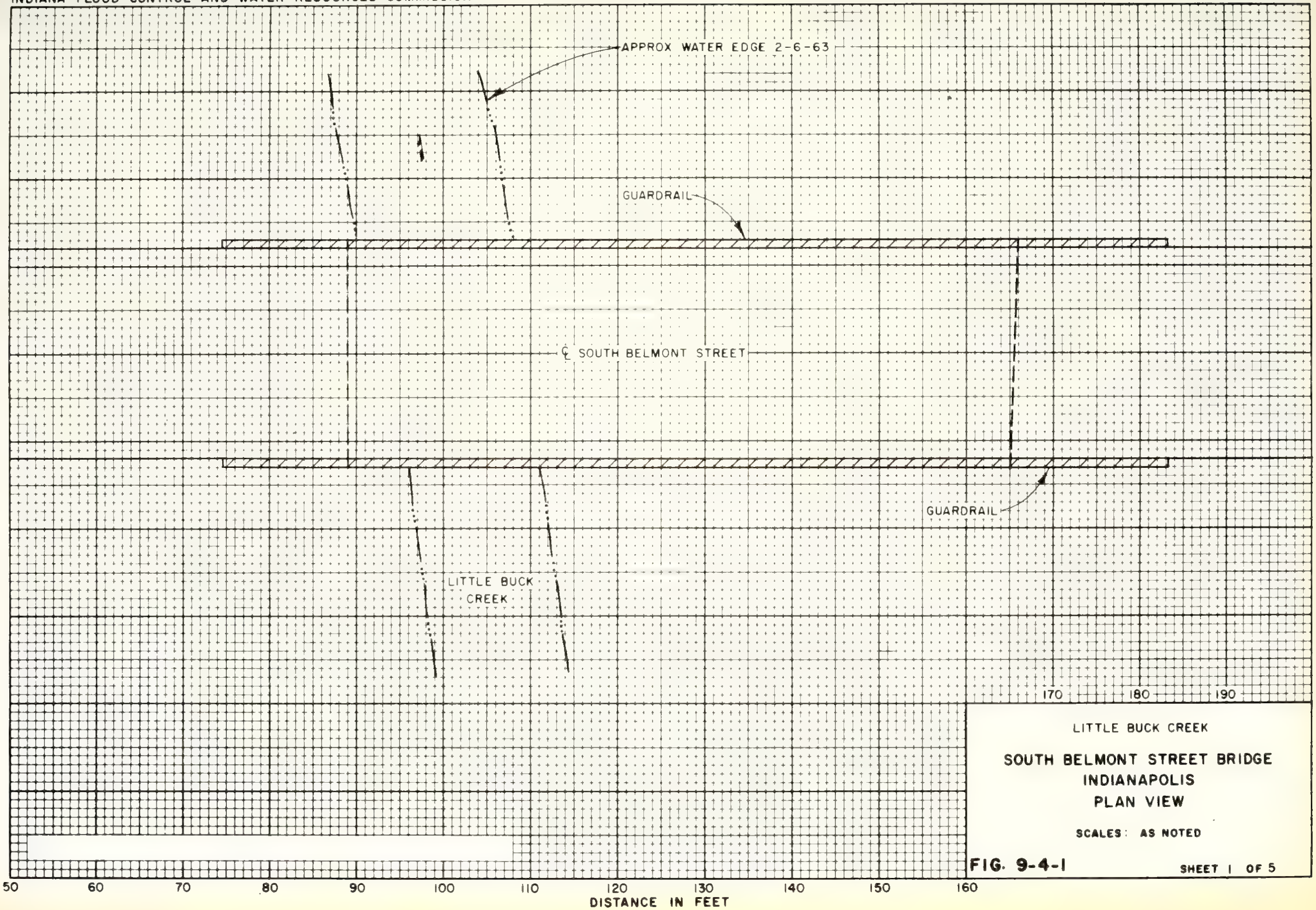
UPSTREAM

SCALES: AS NOTED

FIG. 9-3-5

SHEET 5 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



LITTLE BUCK CREEK

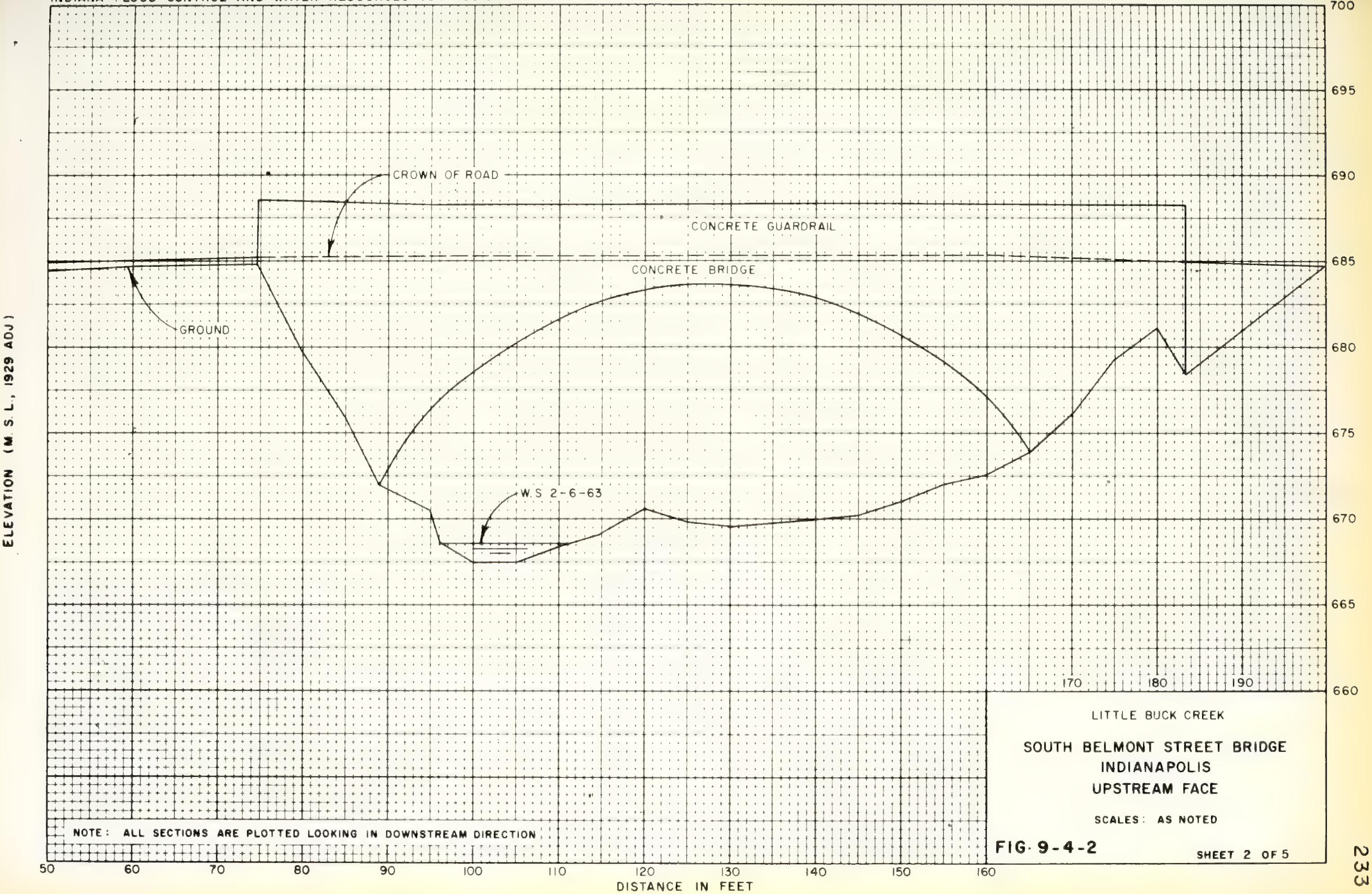
SOUTH BELMONT STREET BRIDGE
INDIANAPOLIS
PLAN VIEW

SCALES: AS NOTED

FIG. 9-4-1

SHEET 1 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



LITTLE BUCK CREEK

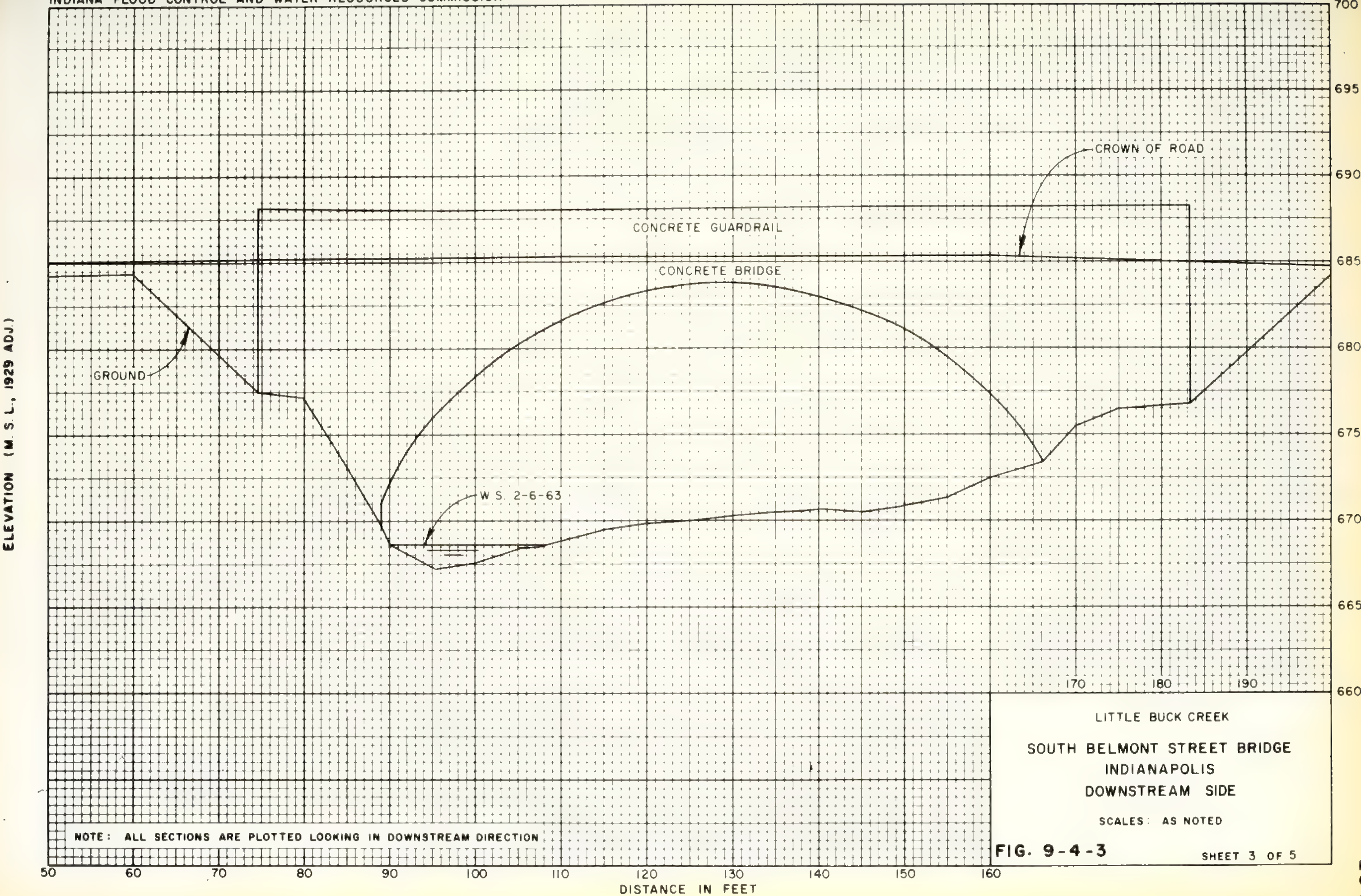
SOUTH BELMONT STREET BRIDGE
INDIANAPOLIS
UPSTREAM FACE

SCALES: AS NOTED

FIG. 9-4-2

SHEET 2 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



LITTLE BUCK CREEK

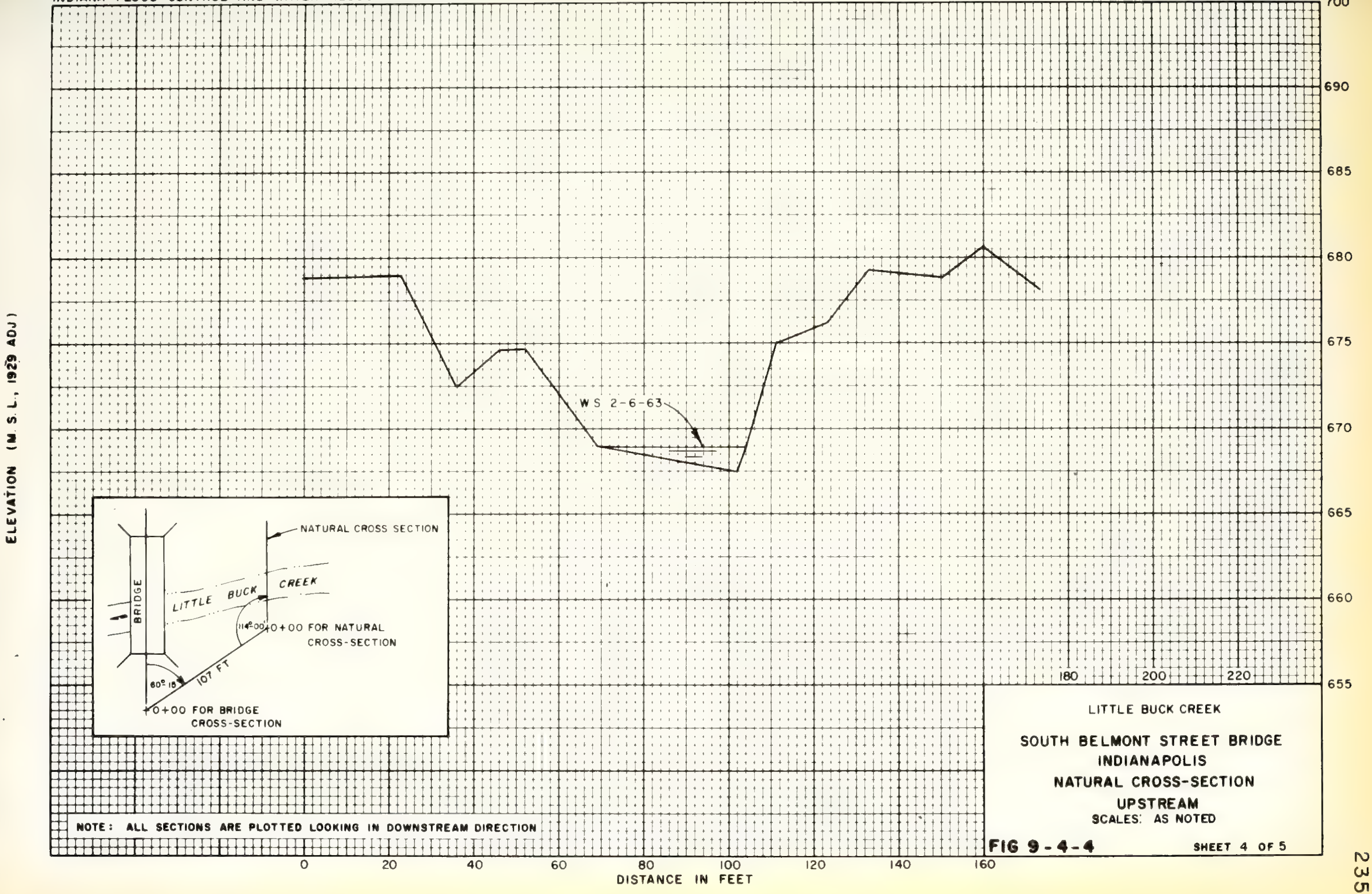
SOUTH BELMONT STREET BRIDGE
INDIANAPOLIS
DOWNSTREAM SIDE

SCALES: AS NOTED

FIG. 9-4-3

SHEET 3 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



NOTE: ALL SECTIONS ARE PLOTTED LOOKING IN DOWNSTREAM DIRECTION

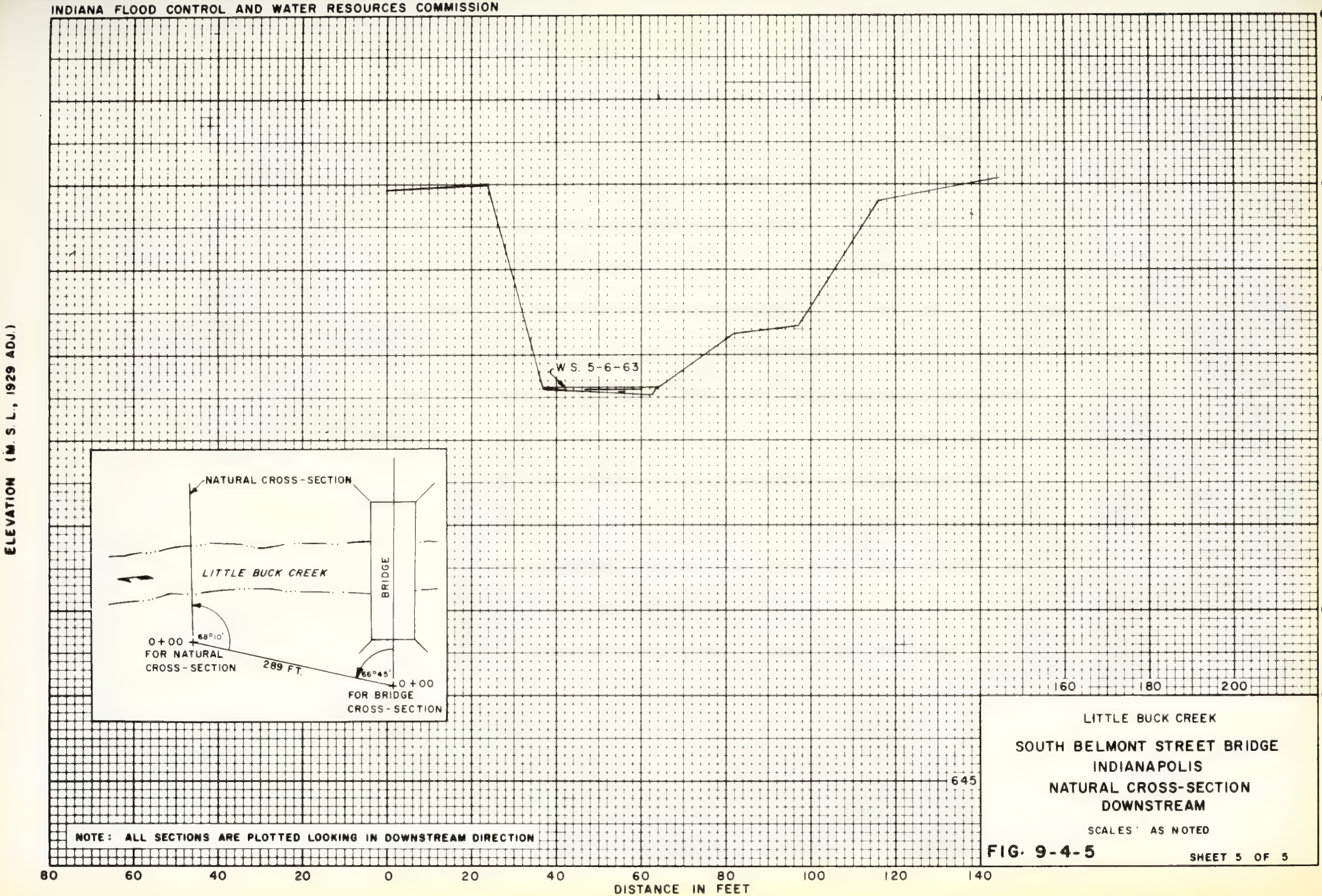
LITTLE BUCK CREEK

SOUTH BELMONT STREET BRIDGE
INDIANAPOLIS
NATURAL CROSS-SECTION
UPSTREAM
SCALES: AS NOTED

FIG 9-4-4

SHEET 4 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



NOTE: ALL SECTIONS ARE PLOTTED LOOKING IN DOWNSTREAM DIRECTION

LITTLE BUCK CREEK

SOUTH BELMONT STREET BRIDGE
INDIANAPOLIS
NATURAL CROSS-SECTION
DOWNSTREAM

SCALES: AS NOTED

FIG. 9-4-5

SHEET 5 OF 5

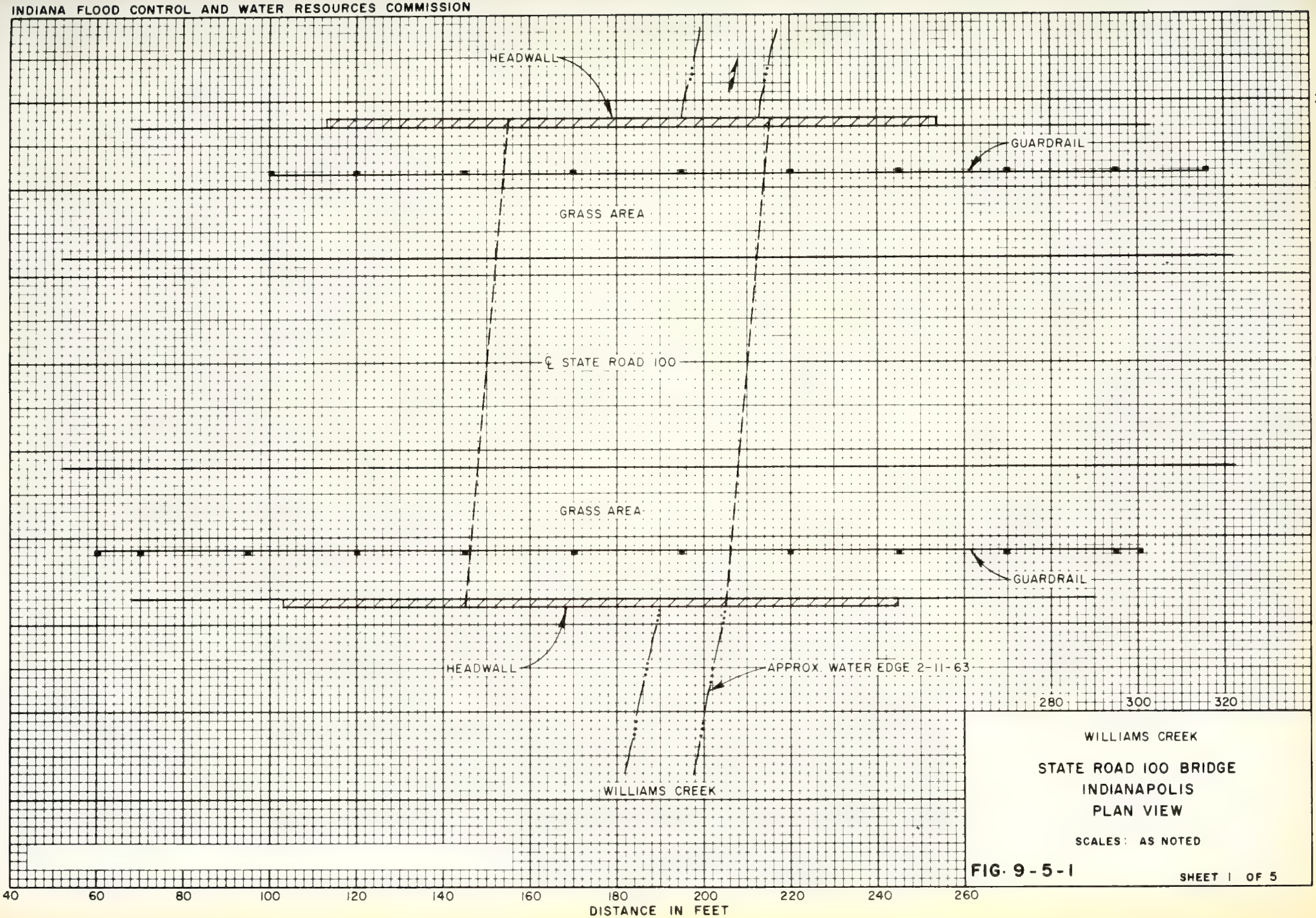
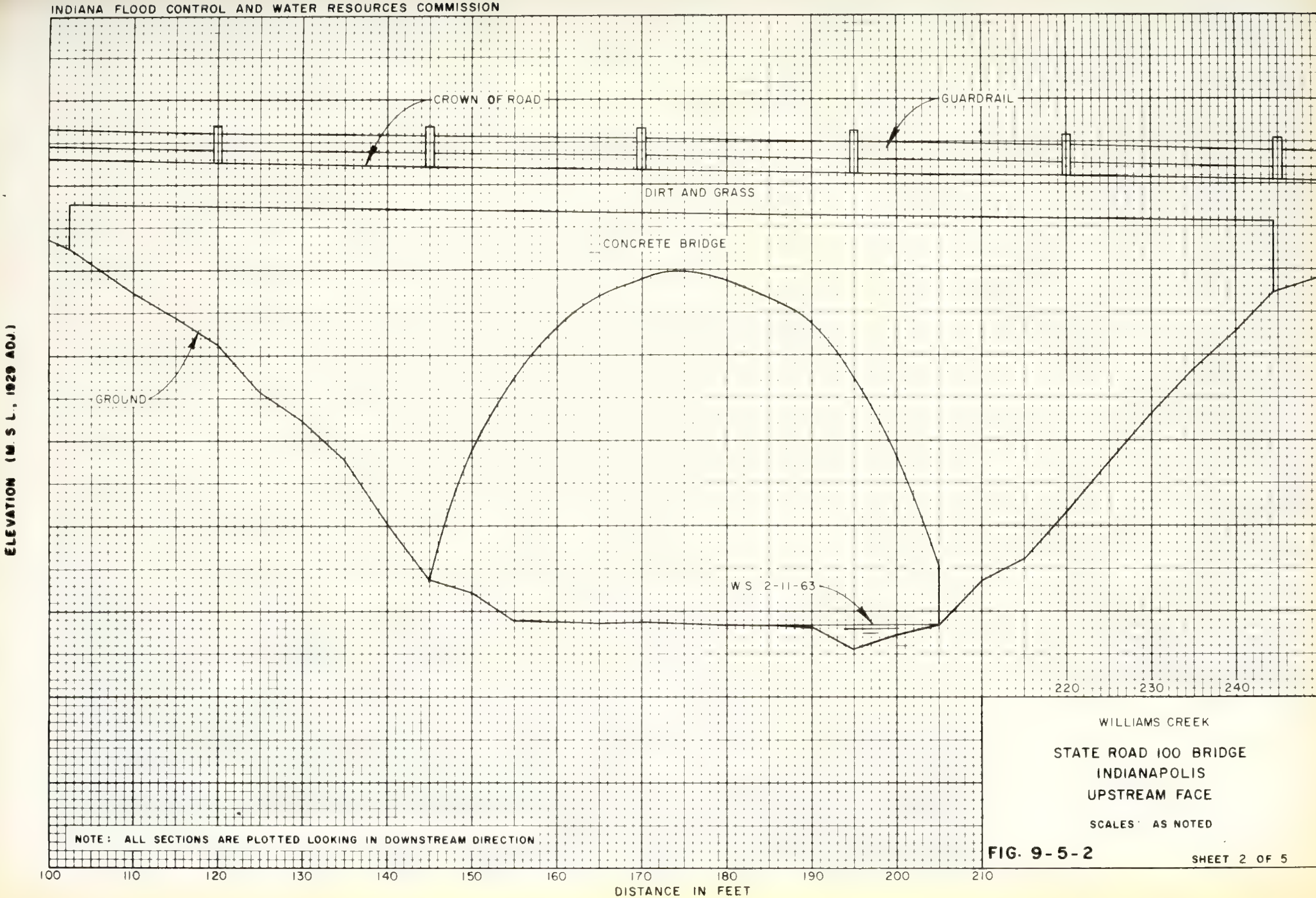

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION
30
20
10
℄
10
20
30
HEADWALL
GRASS AREA
℄ STATE ROAD 100
GRASS AREA
HEADWALL
WILLIAMS CREEK
GUARDRAIL
GUARDRAIL
APPROX. WATER EDGE 2-11-63
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
DISTANCE IN FEET
WILLIAMS CREEK
STATE ROAD 100 BRIDGE
INDIANAPOLIS
PLAN VIEW
SCALES: AS NOTED
SHEET 1 OF 5

FIG. 9-5-1

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



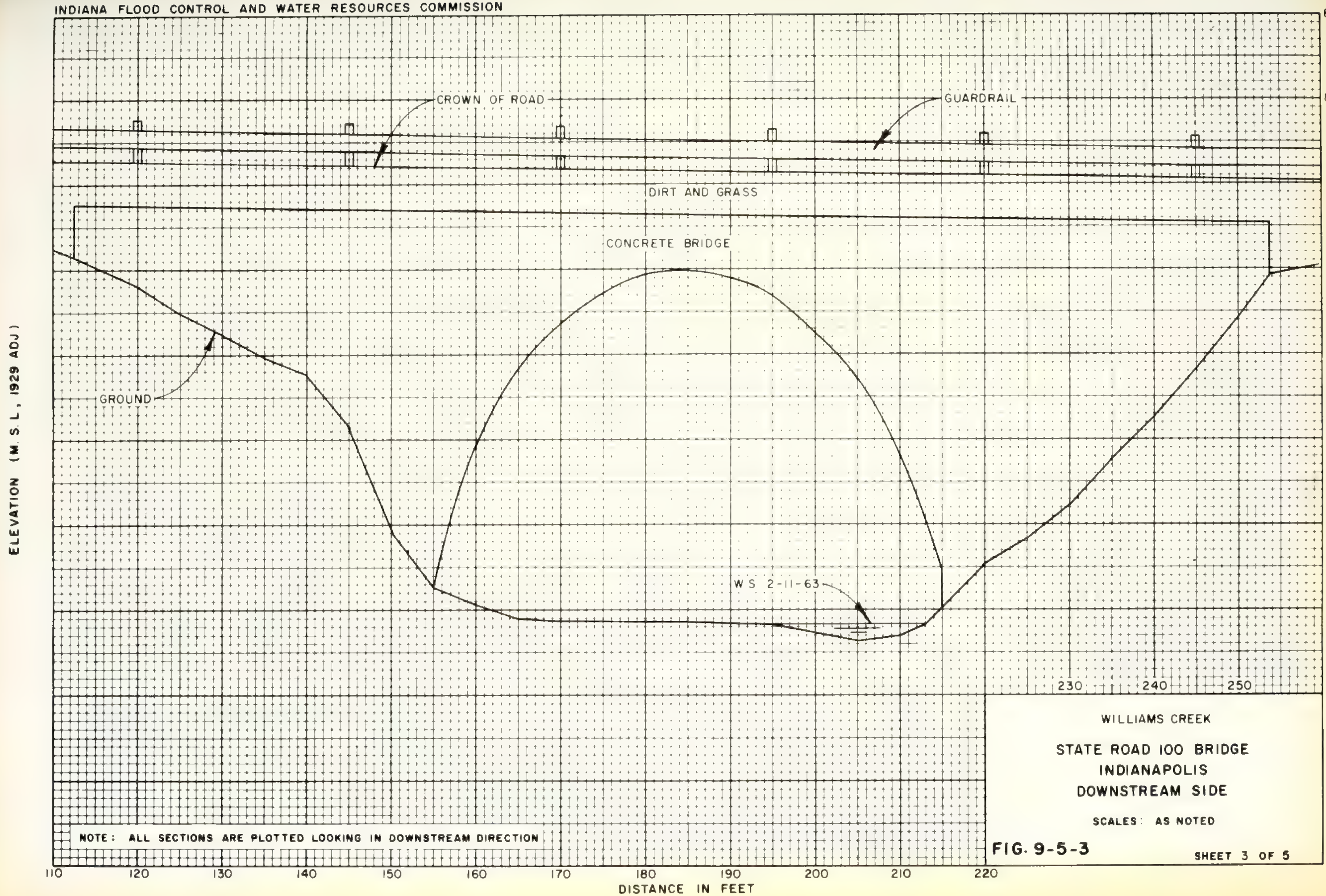
WILLIAMS CREEK

STATE ROAD 100 BRIDGE
INDIANAPOLIS
UPSTREAM FACE

SCALES: AS NOTED

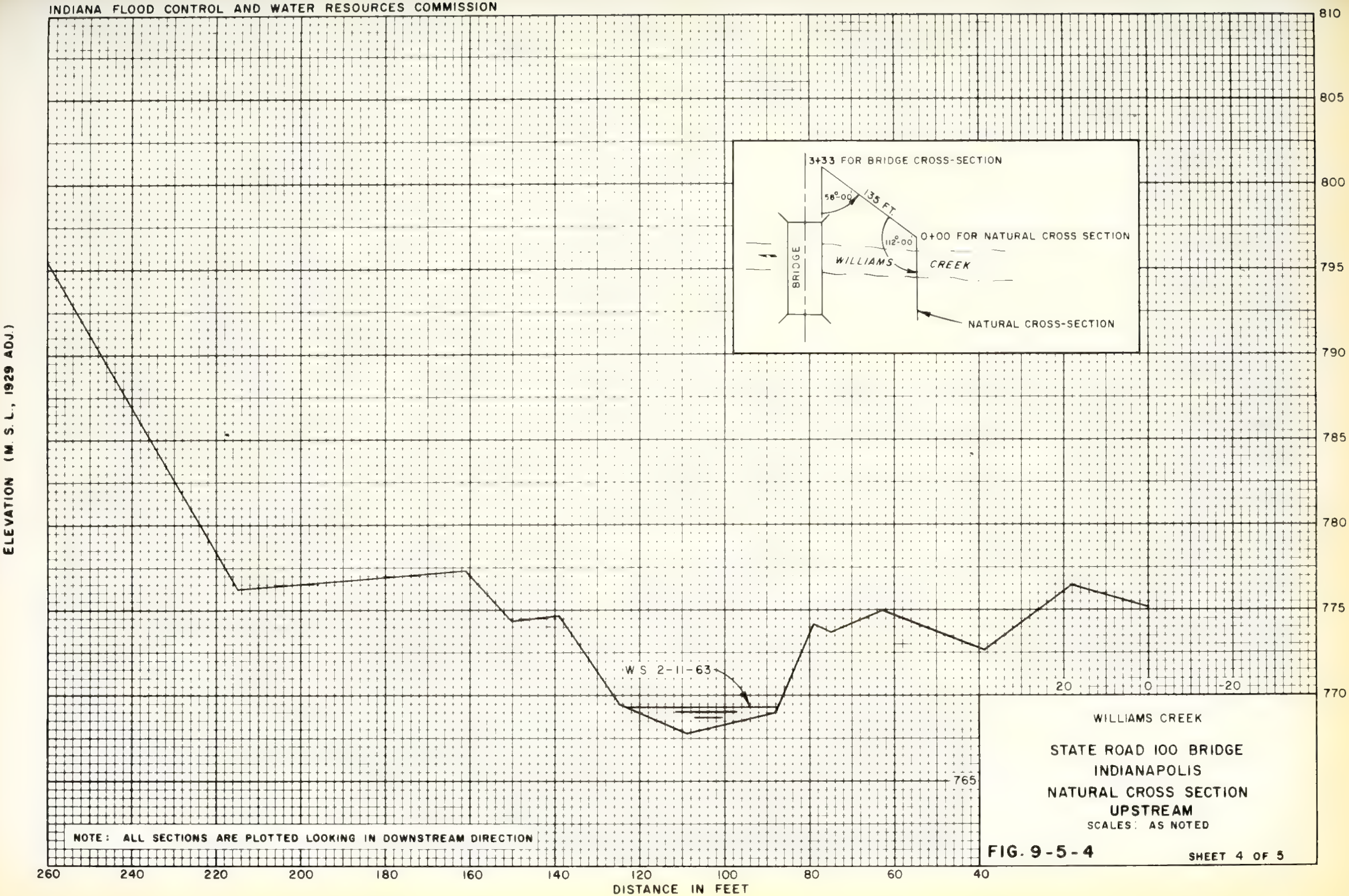
FIG. 9-5-2

SHEET 2 OF 5



INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION
CROWN OF ROAD
GUARDRAIL
DIRT AND GRASS
CONCRETE BRIDGE
GROUND
W S 2-11-63
ELEVATION (M. S. L., 1929 ADJ)
805
800
795
790
785
780
775
770
765
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
DISTANCE IN FEET
NOTE: ALL SECTIONS ARE PLOTTED LOOKING IN DOWNSTREAM DIRECTION
WILLIAMS CREEK
STATE ROAD 100 BRIDGE
INDIANAPOLIS
DOWNSTREAM SIDE
SCALES: AS NOTED
SHEET 3 OF 5

FIG. 9-5-3



NOTE: ALL SECTIONS ARE PLOTTED LOOKING IN DOWNSTREAM DIRECTION

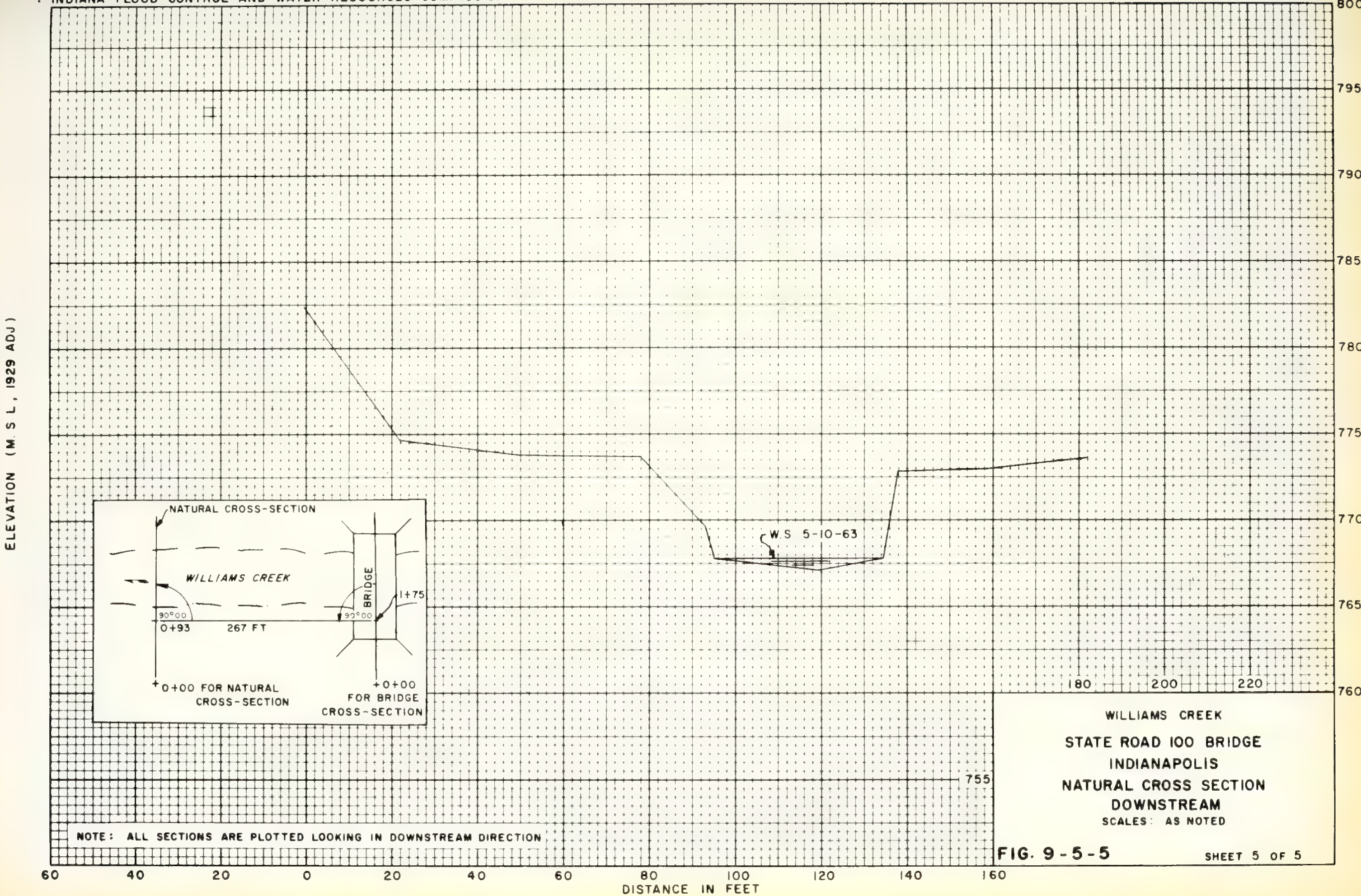
WILLIAMS CREEK

STATE ROAD 100 BRIDGE
INDIANAPOLIS
NATURAL CROSS SECTION
UPSTREAM
SCALES: AS NOTED

FIG. 9-5-4

SHEET 4 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



WILLIAMS CREEK

STATE ROAD 100 BRIDGE

INDIANAPOLIS

NATURAL CROSS SECTION

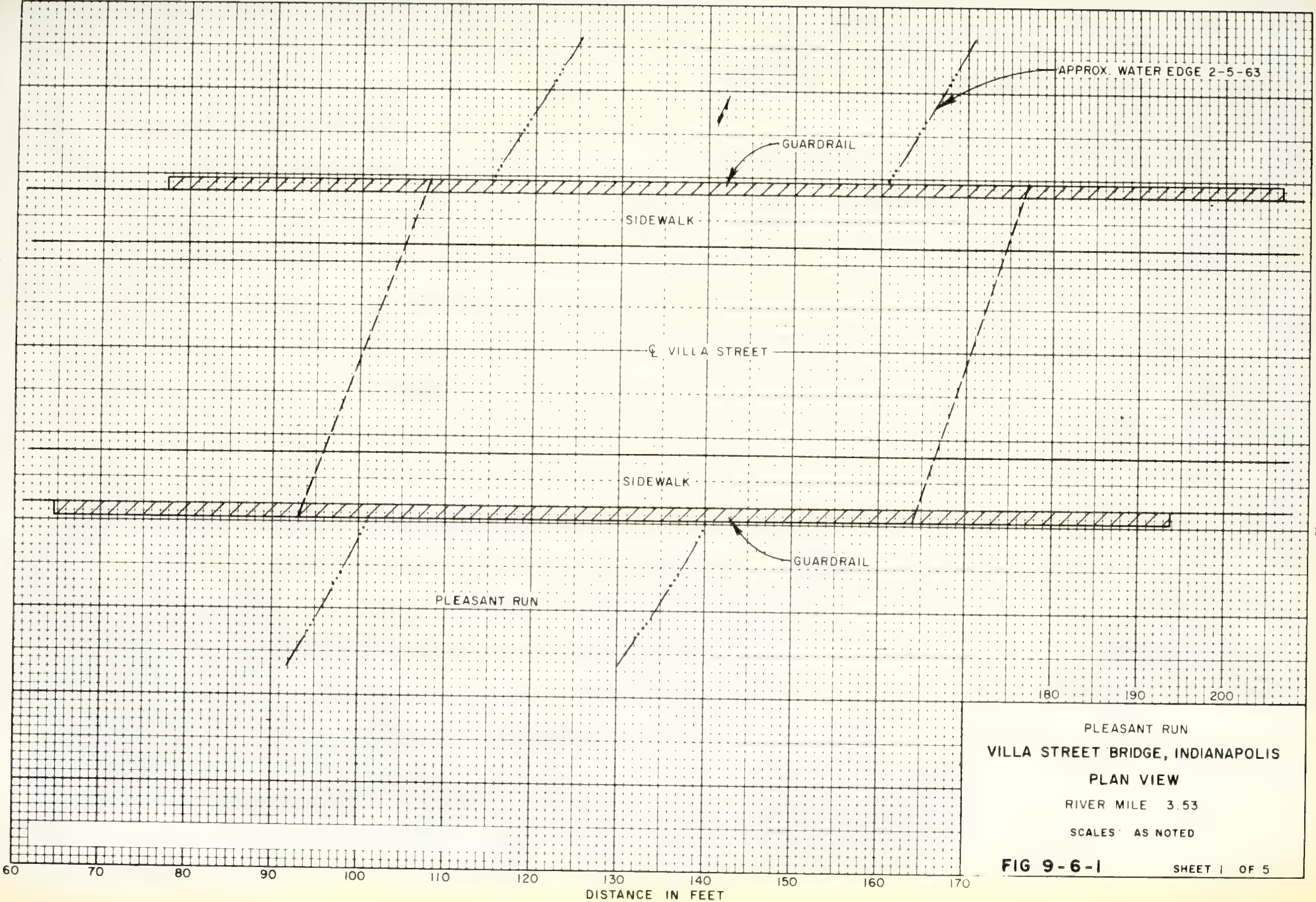
DOWNSTREAM

SCALES: AS NOTED

FIG. 9-5-5

SHEET 5 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



PLEASANT RUN

VILLA STREET BRIDGE, INDIANAPOLIS

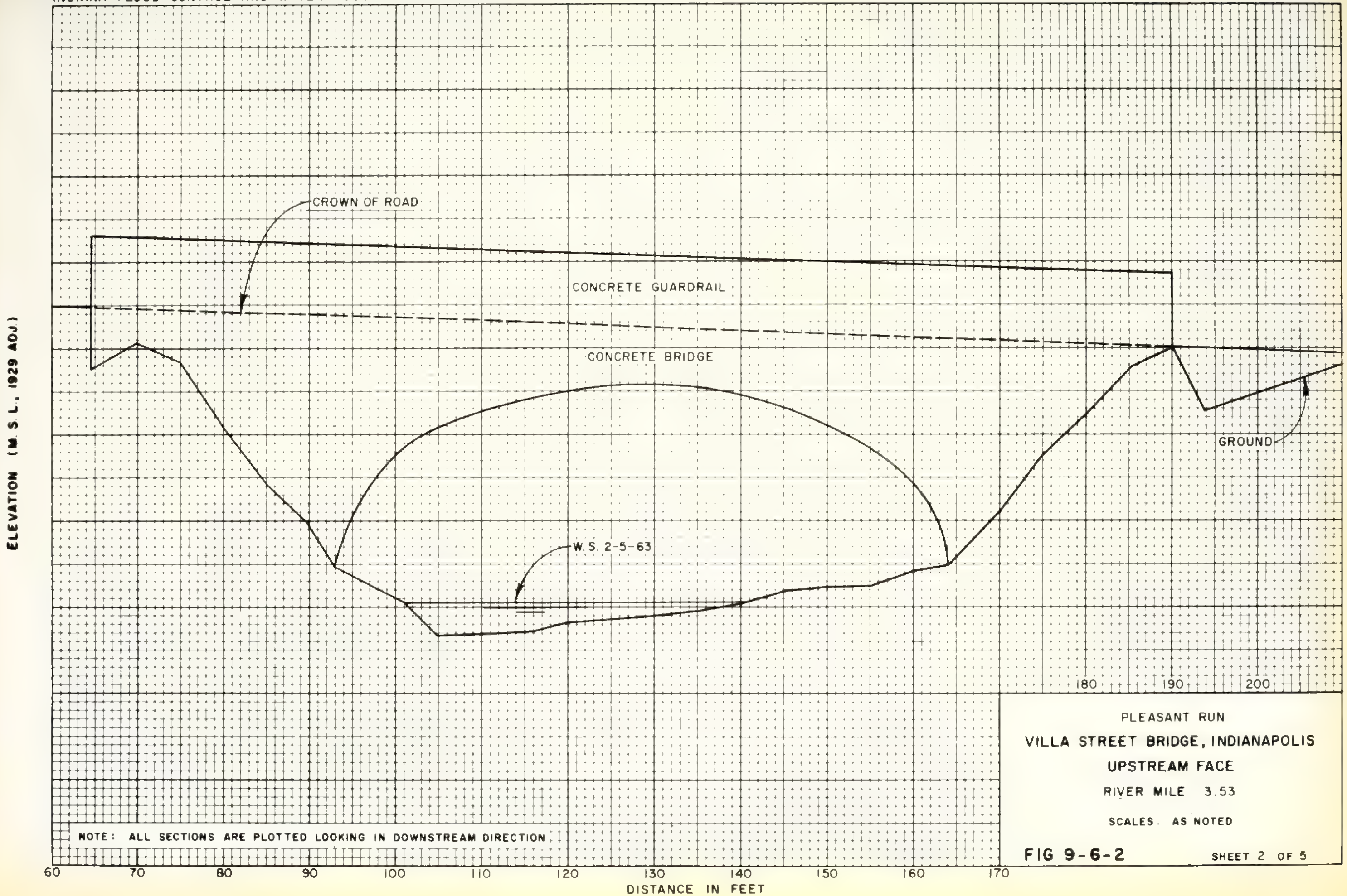
PLAN VIEW

RIVER MILE 3.53

SCALES: AS NOTED

FIG 9-6-1 SHEET 1 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



NOTE: ALL SECTIONS ARE PLOTTED LOOKING IN DOWNSTREAM DIRECTION

PLEASANT RUN

VILLA STREET BRIDGE, INDIANAPOLIS

UPSTREAM FACE

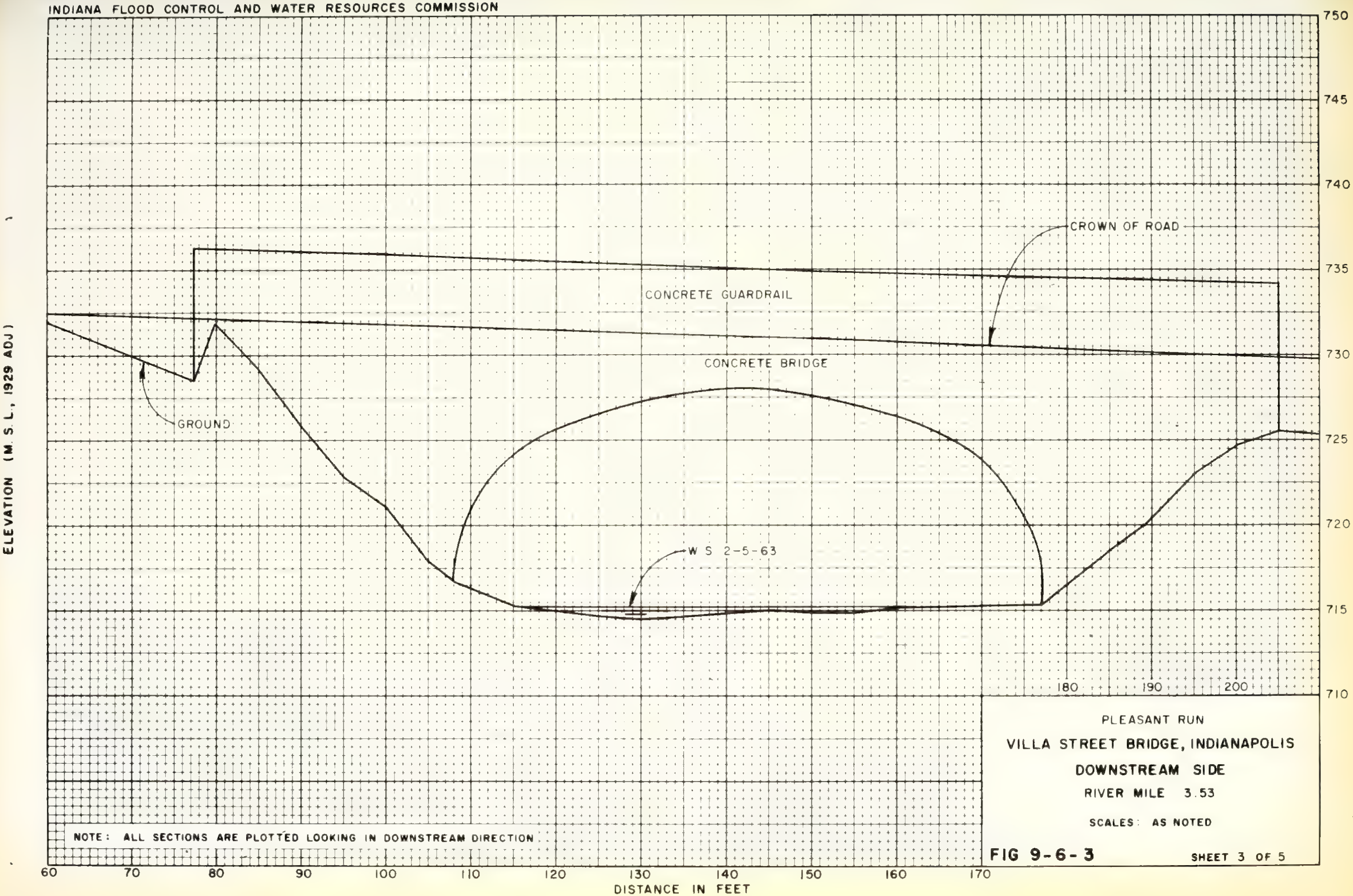
RIVER MILE 3.53

SCALES. AS NOTED

FIG 9-6-2

SHEET 2 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



PLEASANT RUN

VILLA STREET BRIDGE, INDIANAPOLIS

DOWNSTREAM SIDE

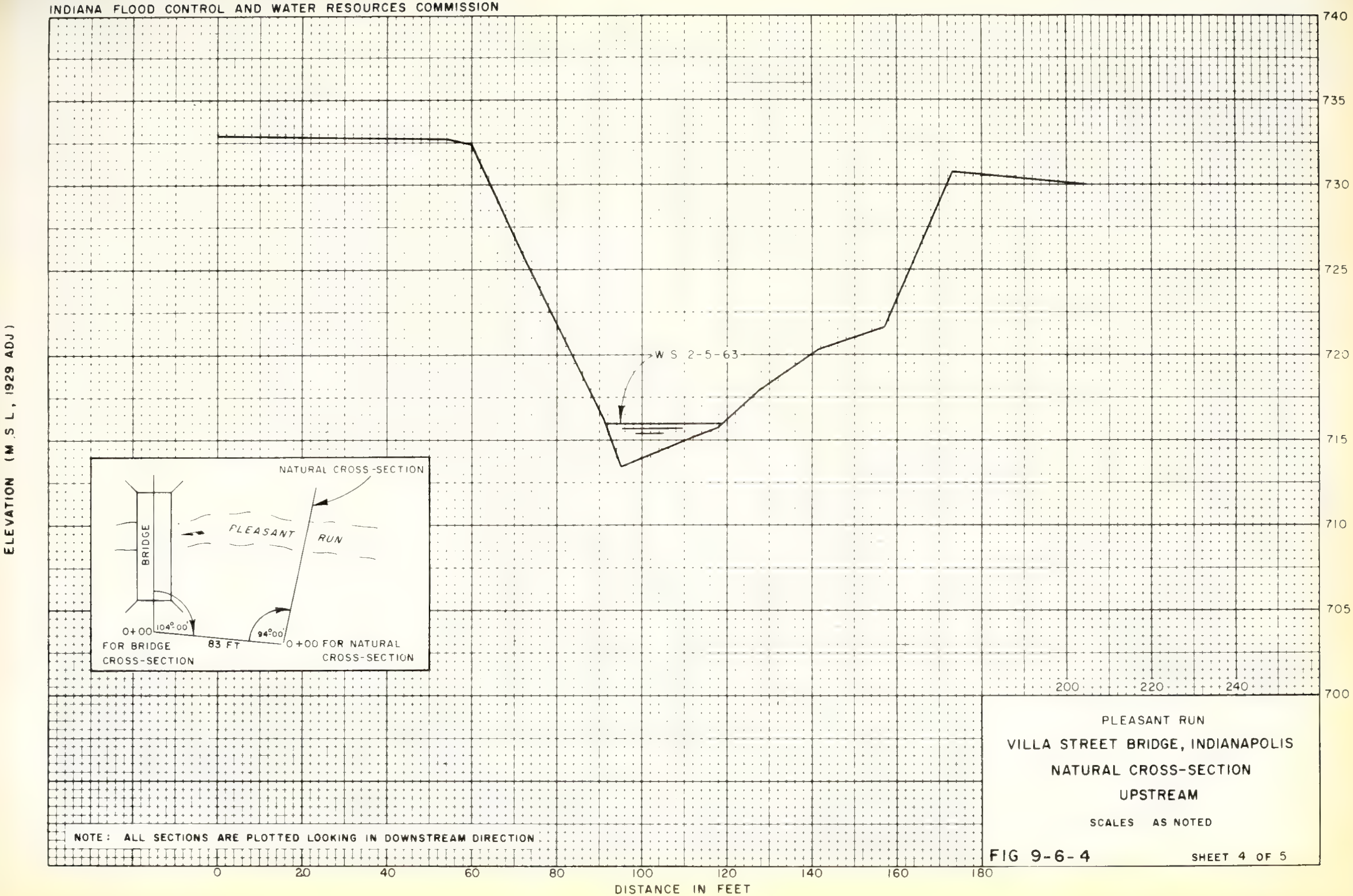
RIVER MILE 3.53

SCALES: AS NOTED

FIG 9-6-3

SHEET 3 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



NOTE: ALL SECTIONS ARE PLOTTED LOOKING IN DOWNSTREAM DIRECTION

PLEASANT RUN

VILLA STREET BRIDGE, INDIANAPOLIS

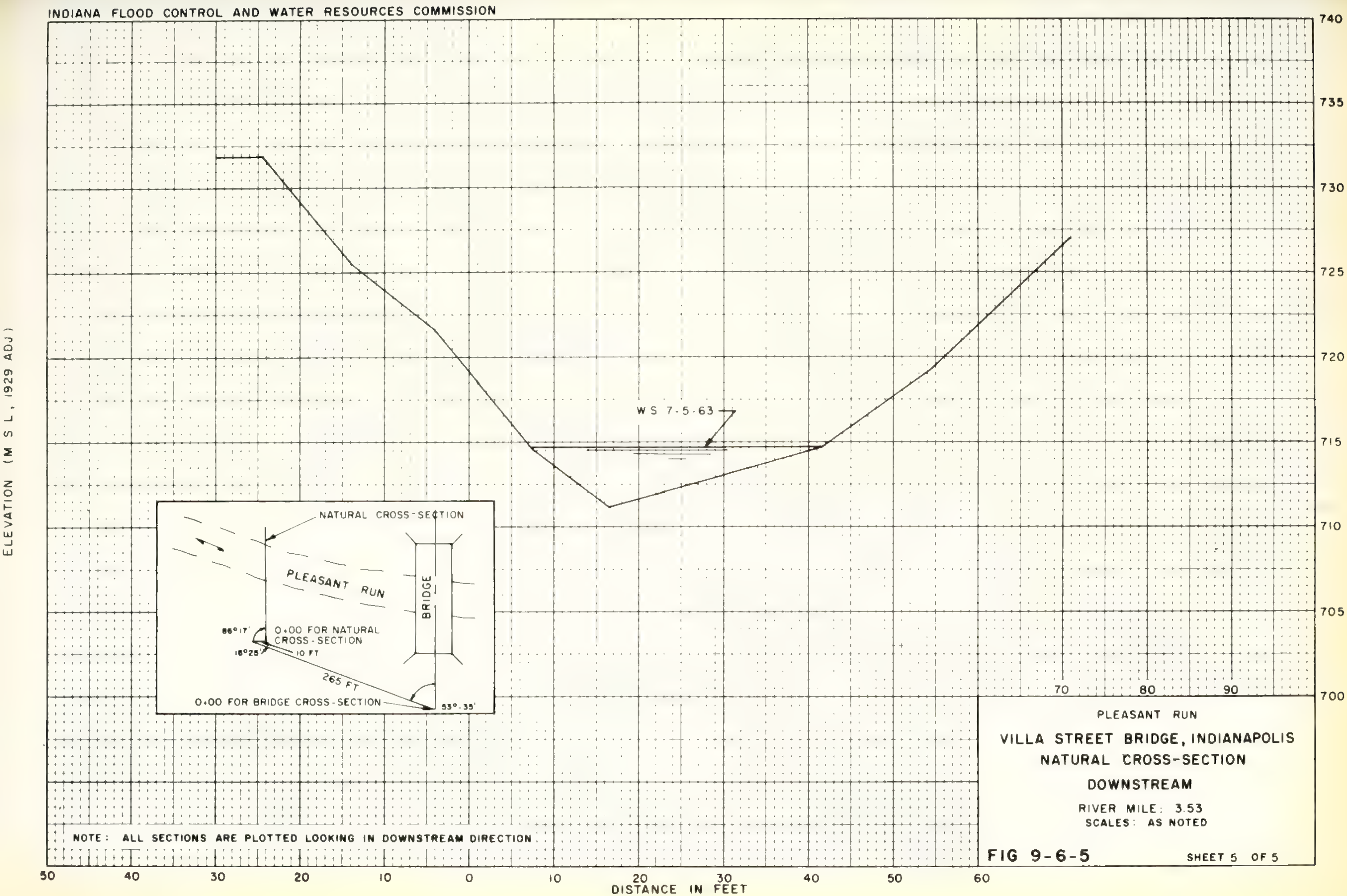
NATURAL CROSS-SECTION

UPSTREAM

SCALES AS NOTED

FIG 9-6-4

SHEET 4 OF 5



PLEASANT RUN

VILLA STREET BRIDGE, INDIANAPOLIS

NATURAL CROSS-SECTION

DOWNSTREAM

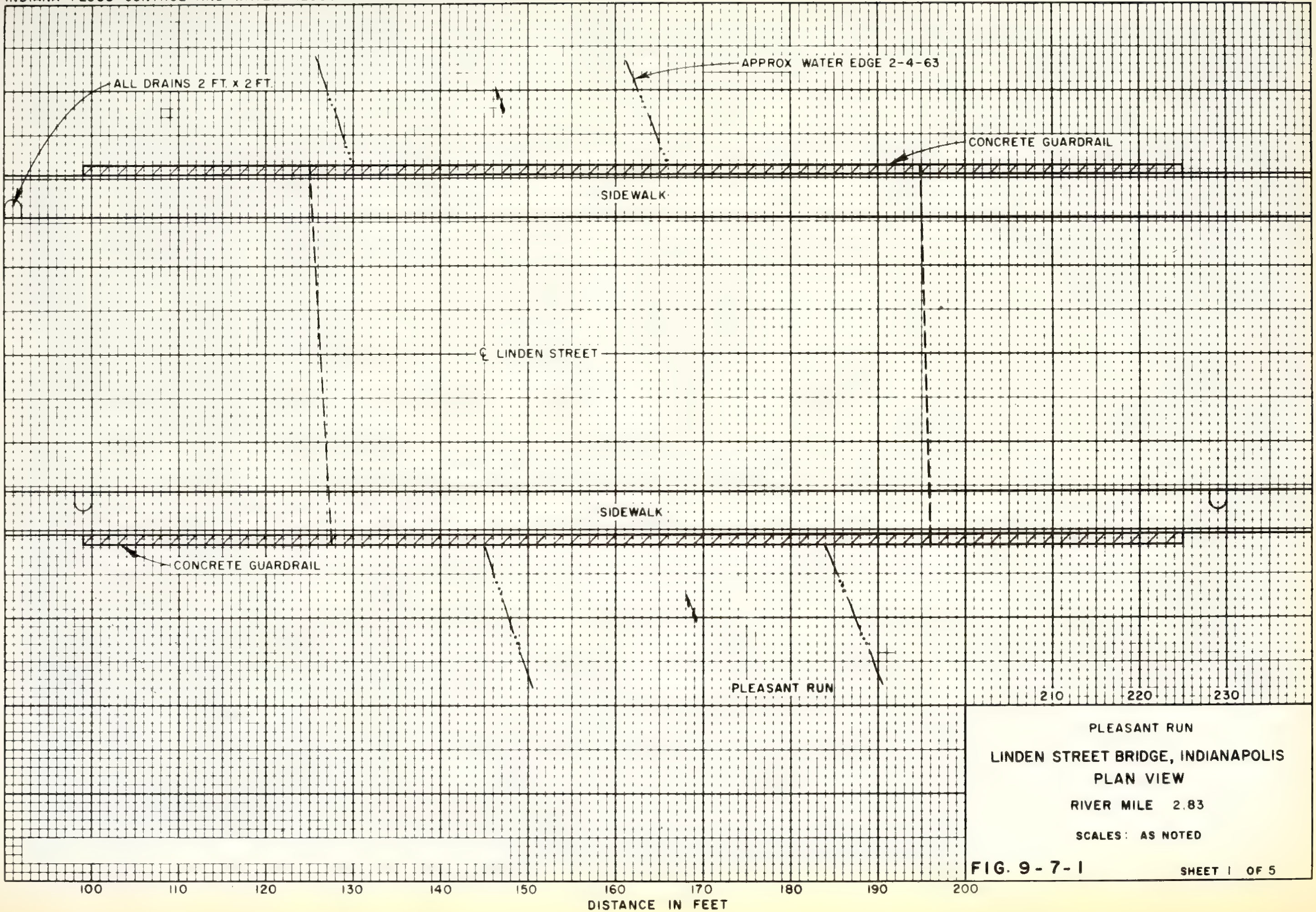
RIVER MILE: 3.53

SCALES: AS NOTED

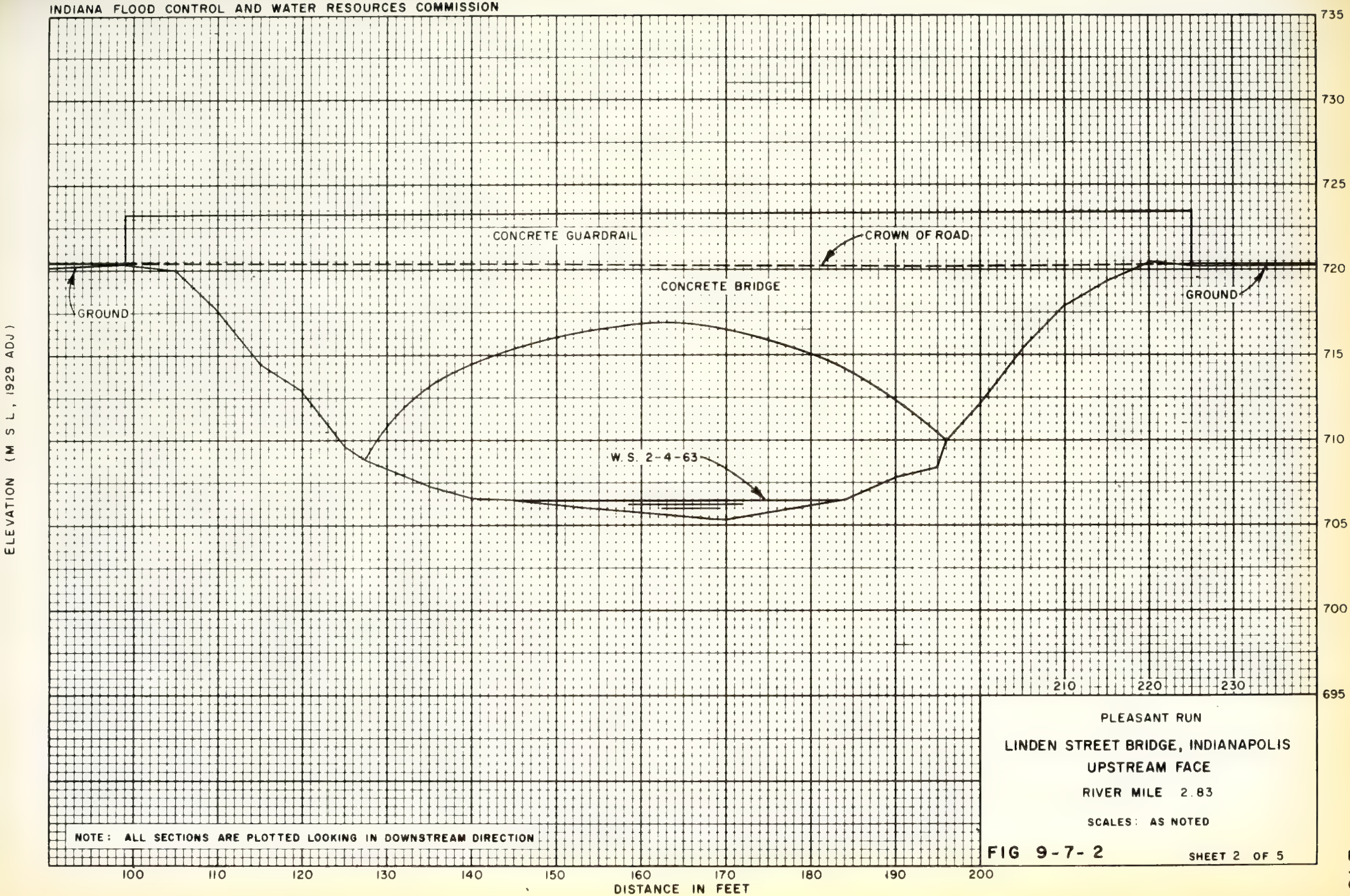
FIG 9-6-5

SHEET 5 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



PLEASANT RUN

LINDEN STREET BRIDGE, INDIANAPOLIS

UPSTREAM FACE

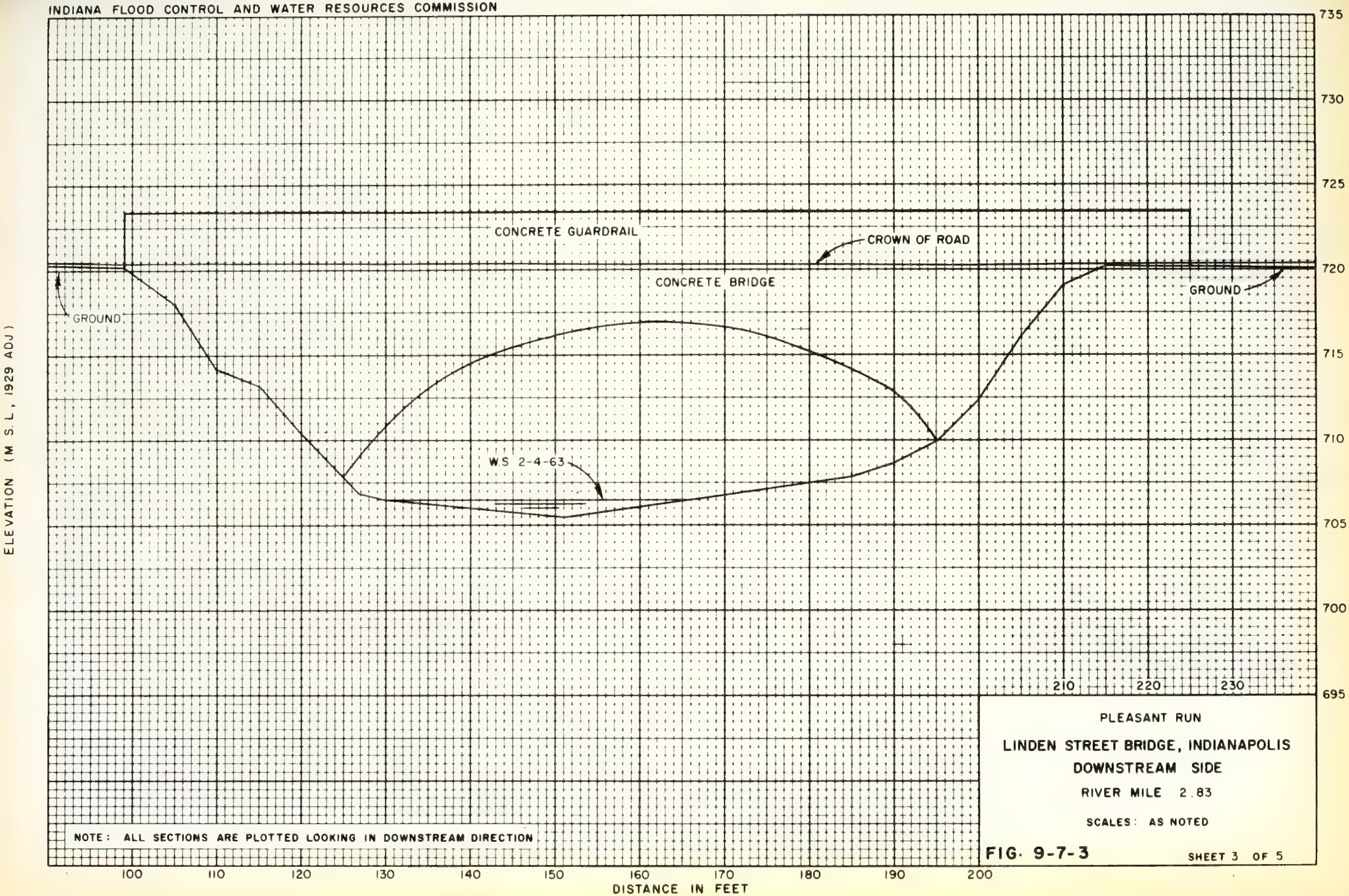
RIVER MILE 2.83

SCALES: AS NOTED

FIG 9-7-2

SHEET 2 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



PLEASANT RUN

LINDEN STREET BRIDGE, INDIANAPOLIS

DOWNSTREAM SIDE

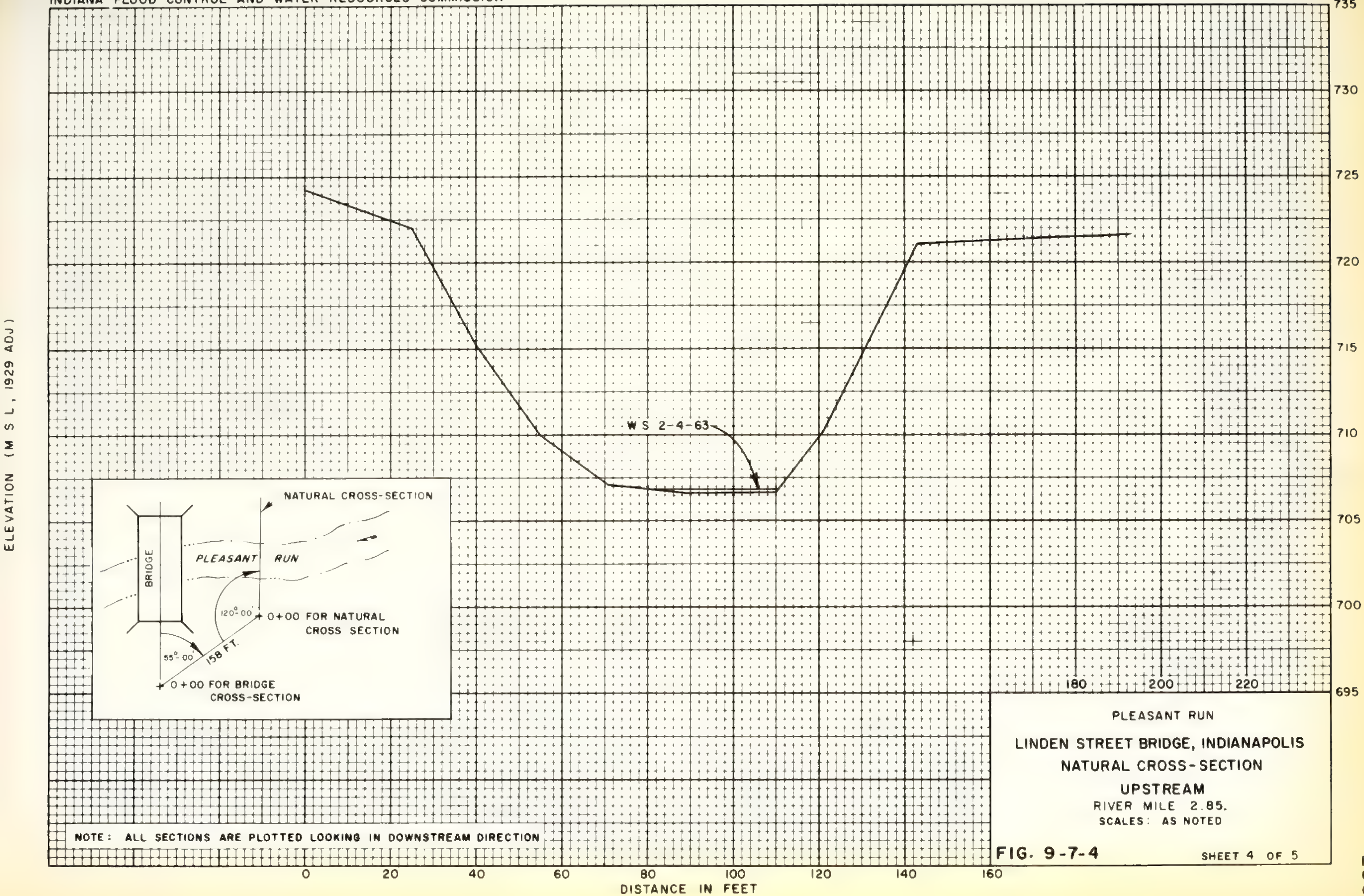
RIVER MILE 2.83

SCALES: AS NOTED

FIG. 9-7-3

SHEET 3 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



NOTE: ALL SECTIONS ARE PLOTTED LOOKING IN DOWNSTREAM DIRECTION

PLEASANT RUN

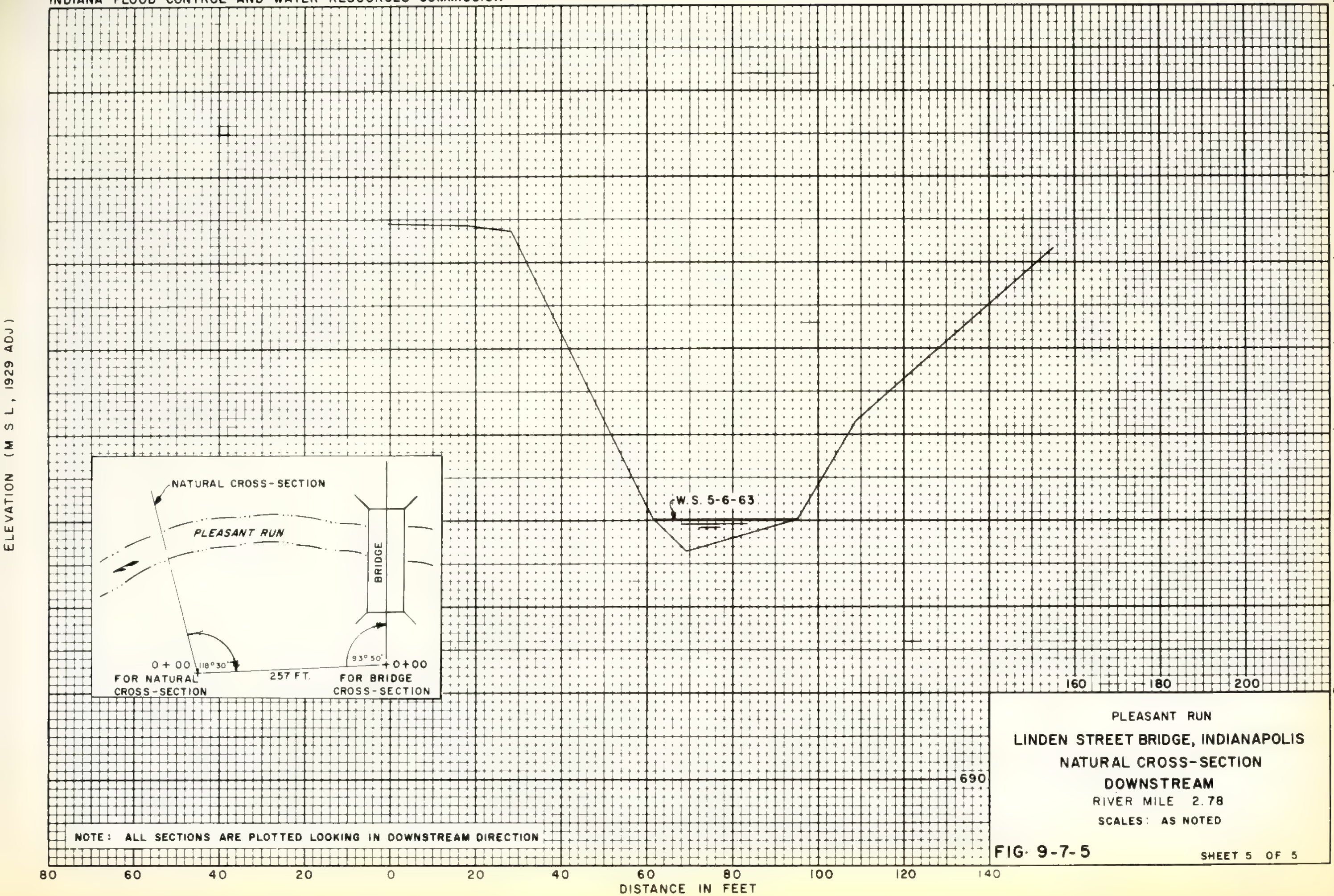
LINDEN STREET BRIDGE, INDIANAPOLIS
NATURAL CROSS-SECTION
UPSTREAM

RIVER MILE 2.85.
SCALES: AS NOTED

FIG. 9-7-4

SHEET 4 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



PLEASANT RUN

LINDEN STREET BRIDGE, INDIANAPOLIS

NATURAL CROSS-SECTION

DOWNSTREAM

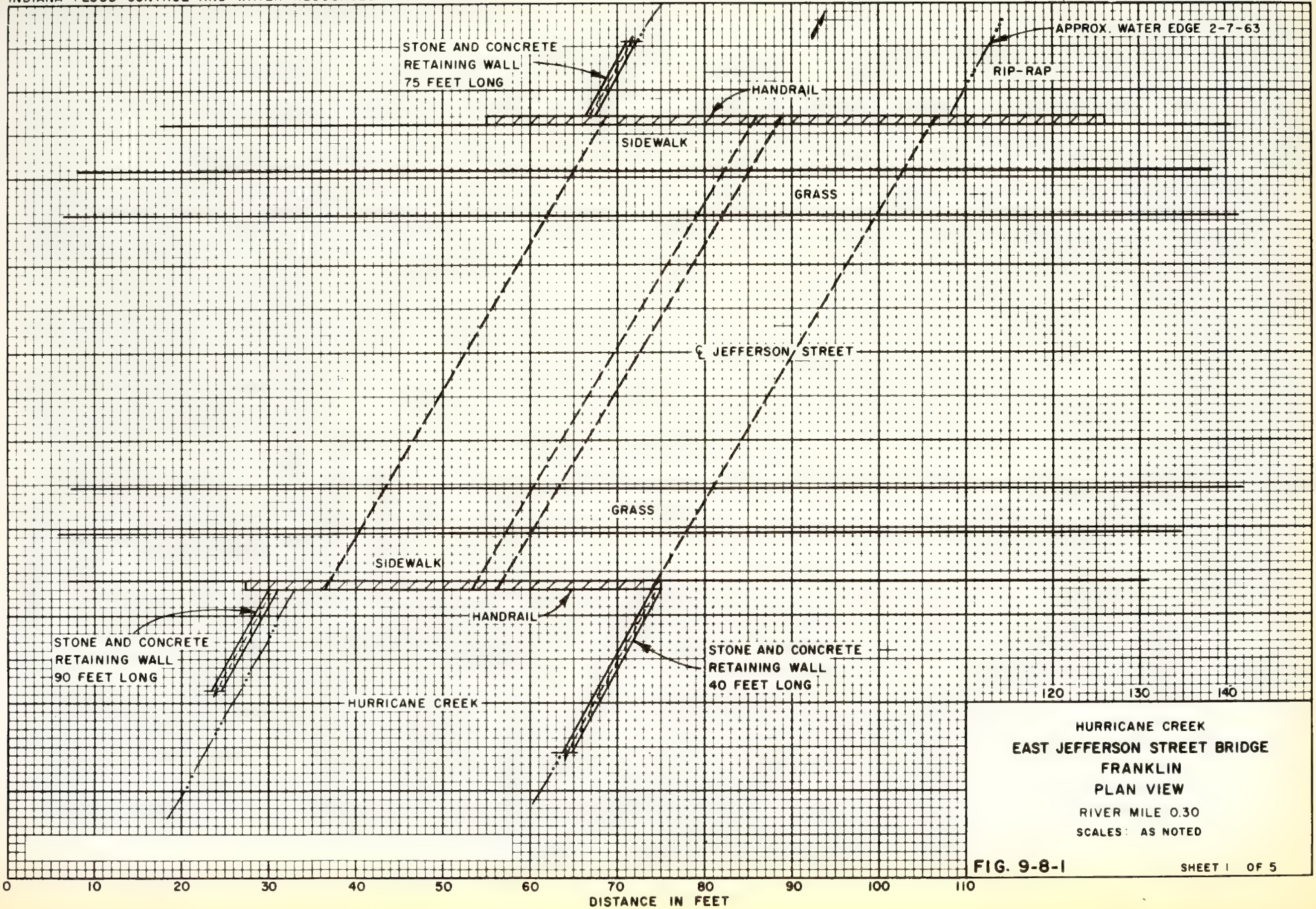
RIVER MILE 2.78

SCALES: AS NOTED

FIG. 9-7-5

SHEET 5 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION

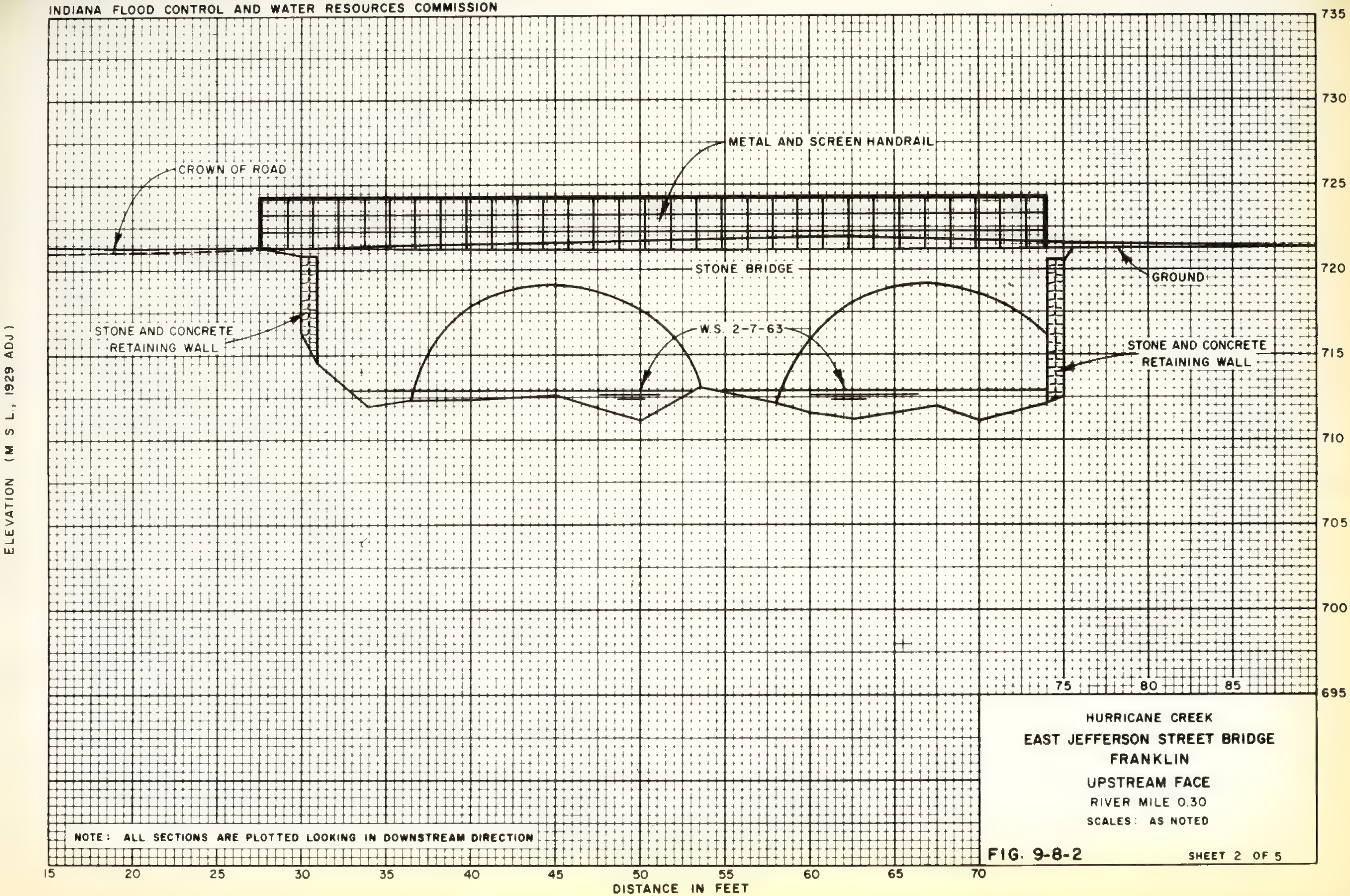


HURRICANE CREEK
EAST JEFFERSON STREET BRIDGE
FRANKLIN
PLAN VIEW
RIVER MILE 0.30
SCALES: AS NOTED

FIG. 9-8-1

SHEET 1 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION

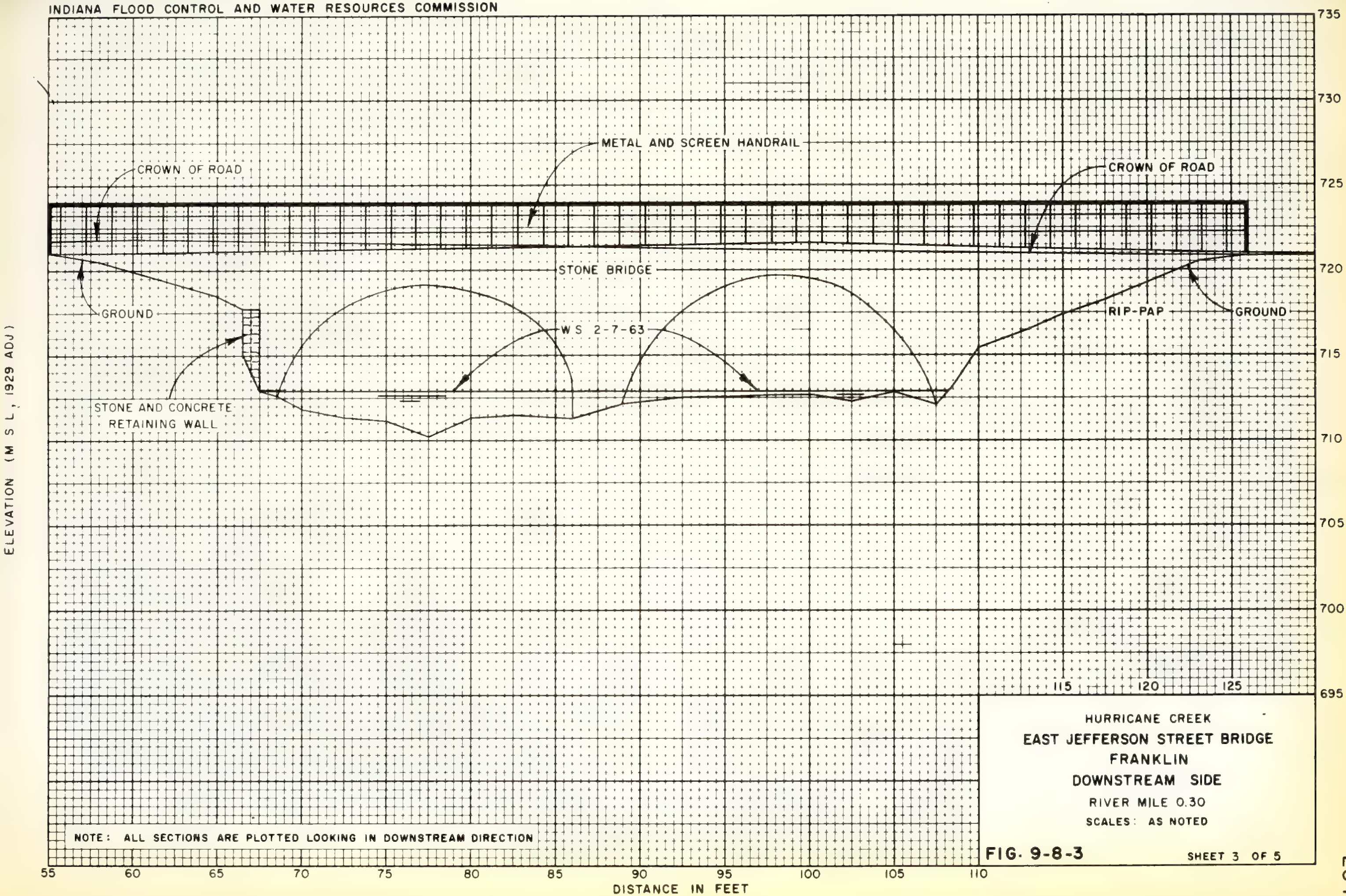


HURRICANE CREEK
EAST JEFFERSON STREET BRIDGE
FRANKLIN
UPSTREAM FACE
RIVER MILE 0.30
SCALES: AS NOTED

FIG. 9-8-2

SHEET 2 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION

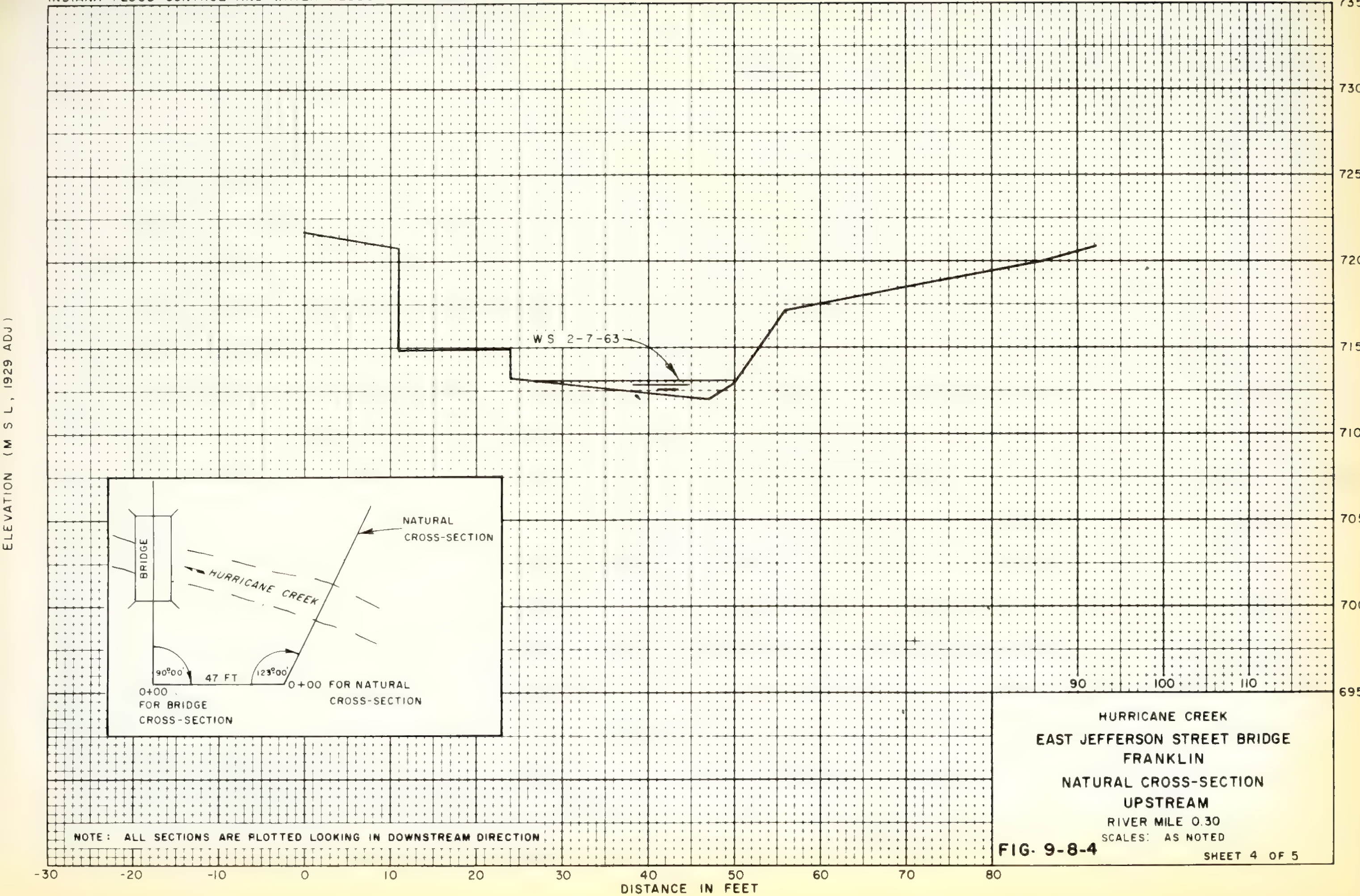


HURRICANE CREEK
EAST JEFFERSON STREET BRIDGE
FRANKLIN
DOWNSTREAM SIDE
RIVER MILE 0.30
SCALES: AS NOTED

FIG. 9-8-3

SHEET 3 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



HURRICANE CREEK

EAST JEFFERSON STREET BRIDGE

FRANKLIN

NATURAL CROSS-SECTION

UPSTREAM

RIVER MILE 0.30

SCALES: AS NOTED

FIG. 9-8-4

SHEET 4 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION

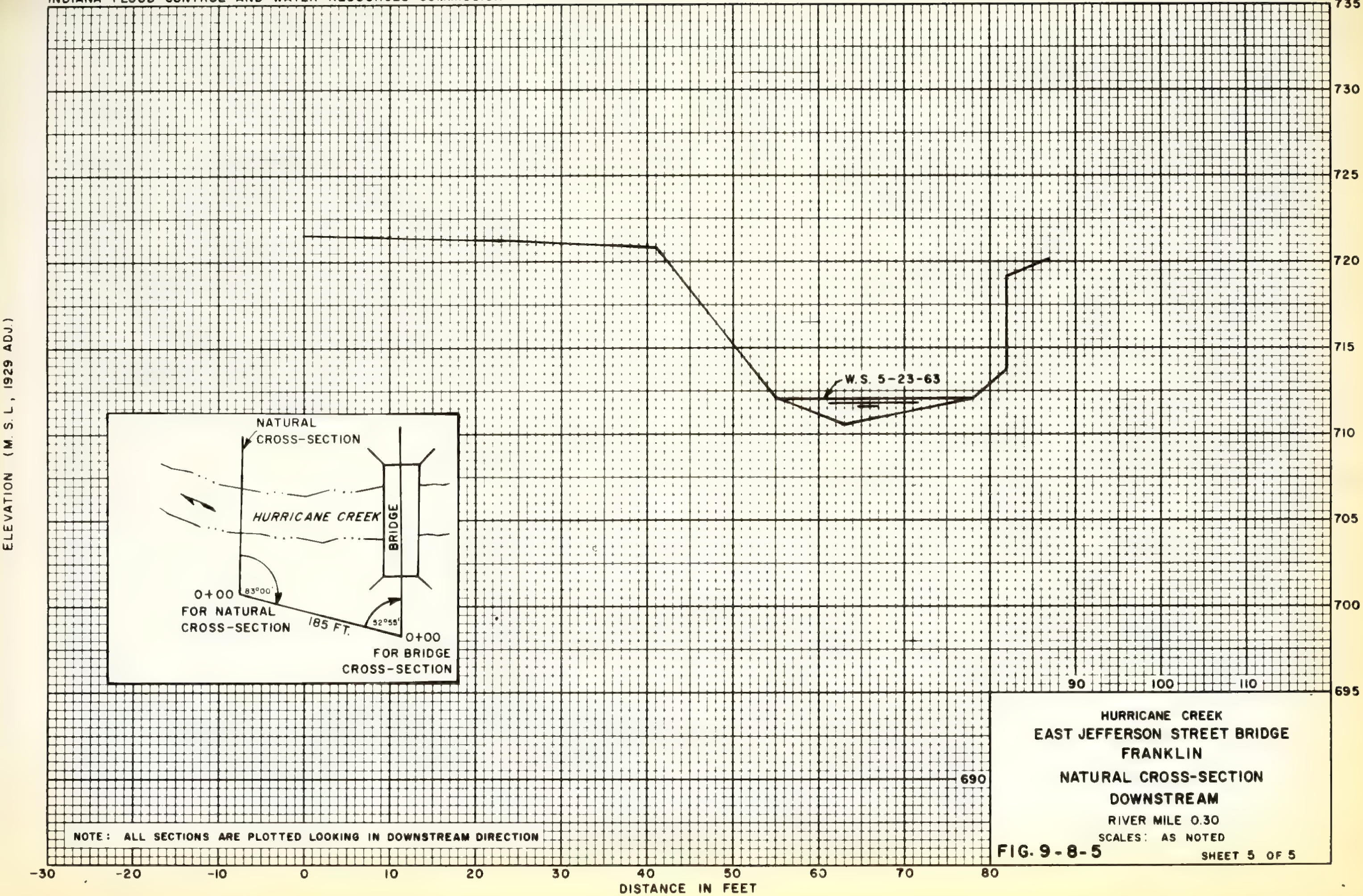
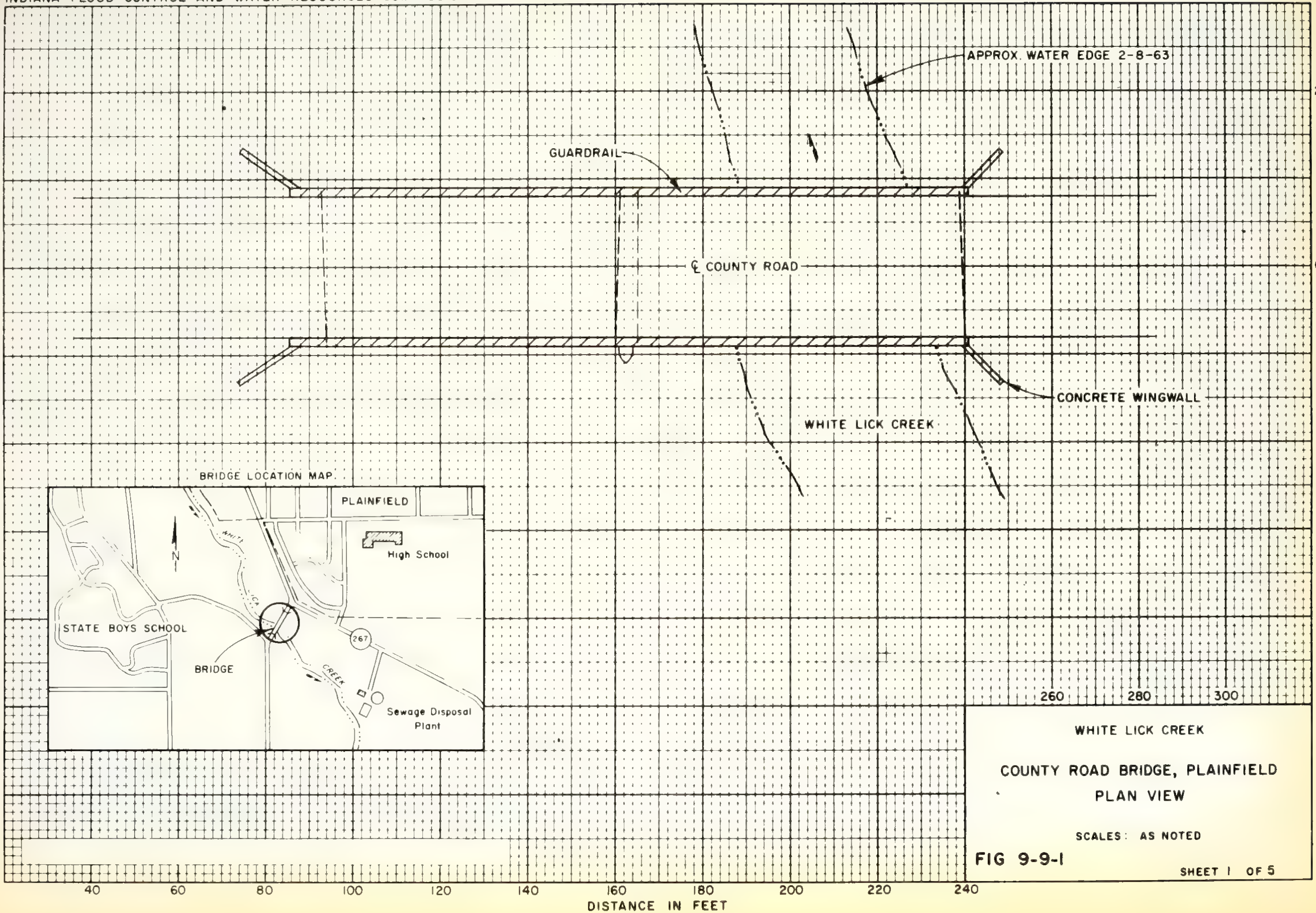


FIG. 9-8-5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



WHITE LICK CREEK

COUNTY ROAD BRIDGE, PLAINFIELD

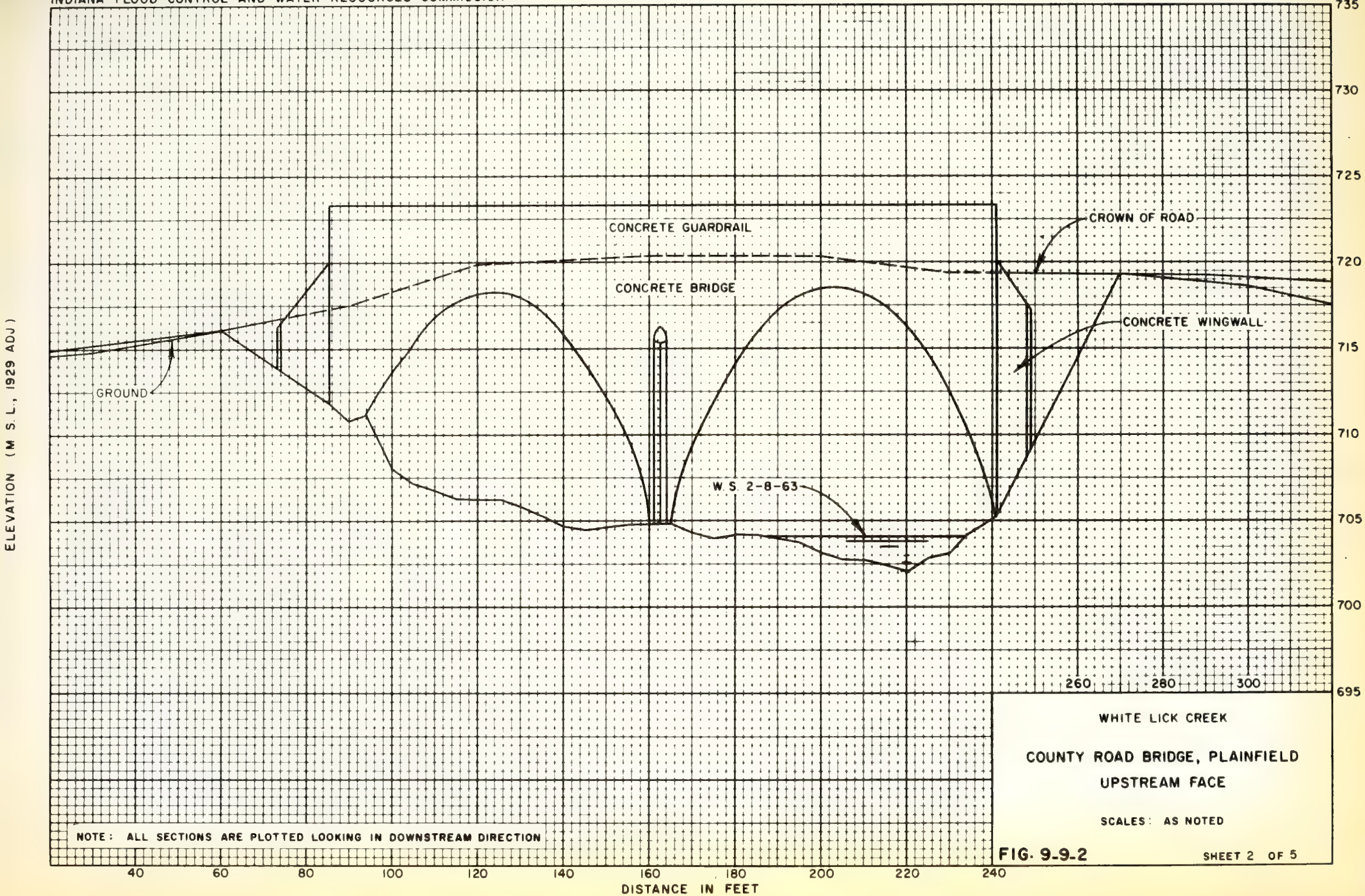
PLAN VIEW

SCALES: AS NOTED

FIG 9-9-1

SHEET 1 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



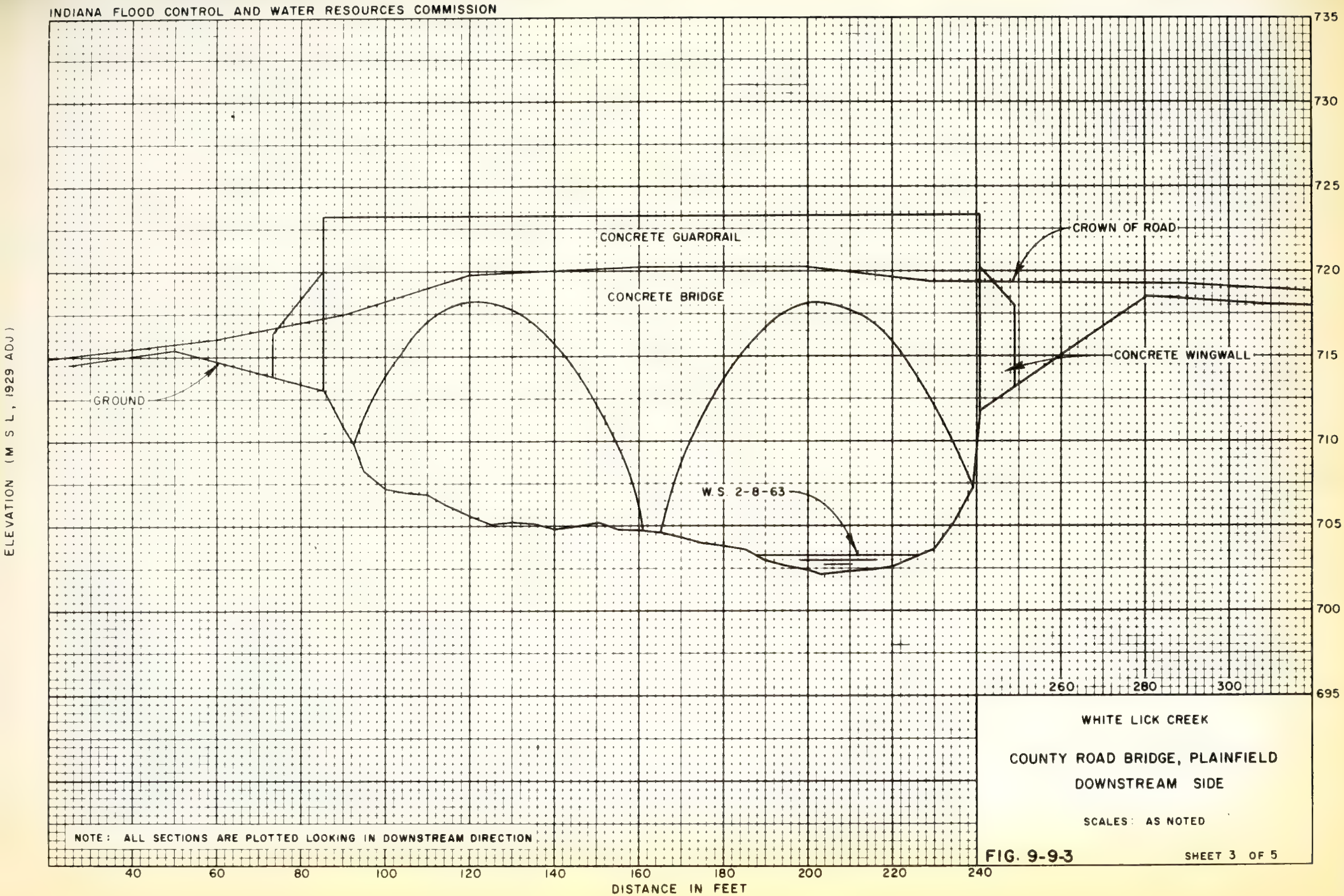
WHITE LICK CREEK

COUNTY ROAD BRIDGE, PLAINFIELD
UPSTREAM FACE

SCALES: AS NOTED

FIG. 9-9-2

SHEET 2 OF 5



WHITE LICK CREEK

COUNTY ROAD BRIDGE, PLAINFIELD

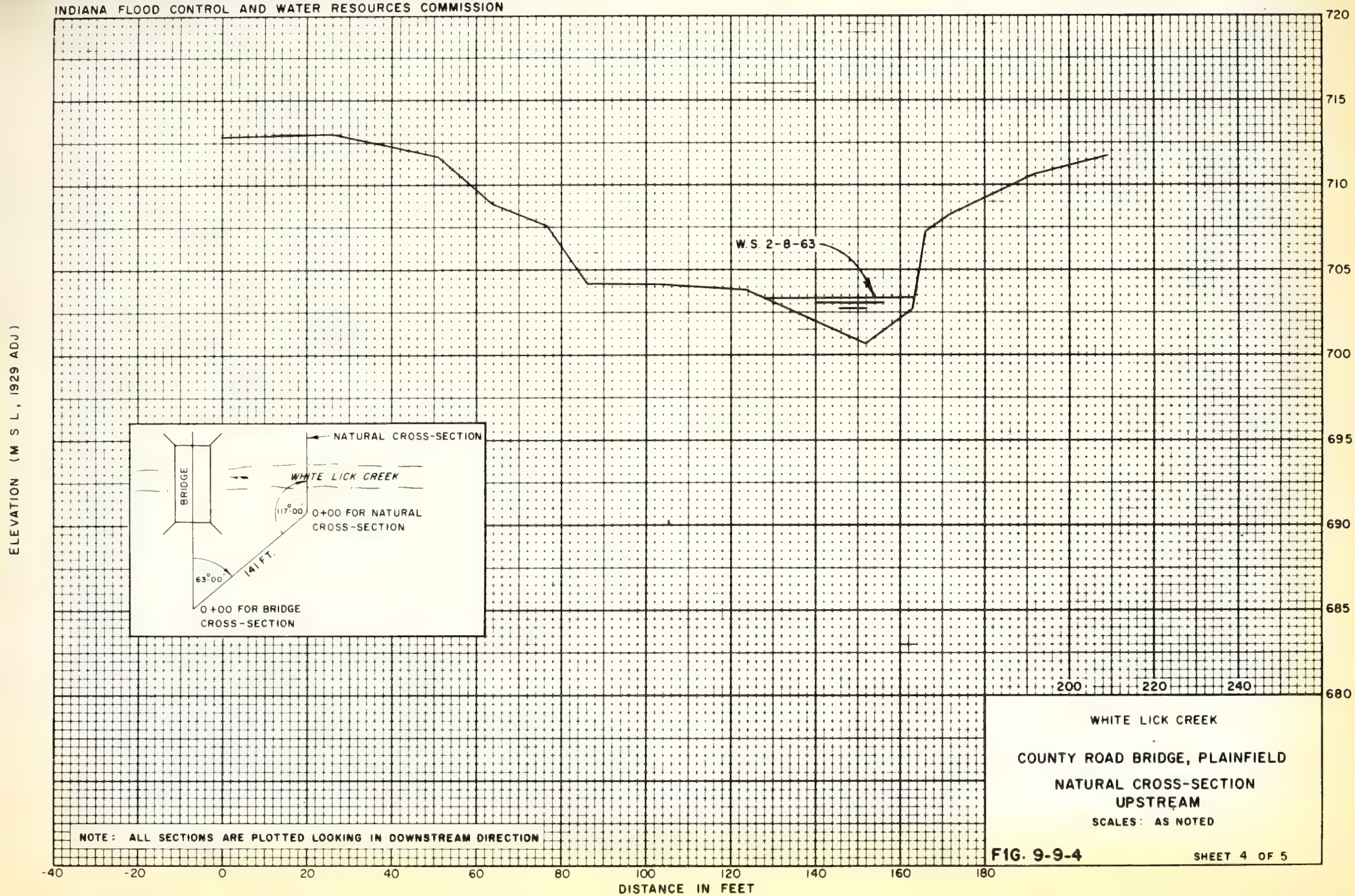
DOWNSTREAM SIDE

SCALES: AS NOTED

FIG. 9-9-3

SHEET 3 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



WHITE LICK CREEK

COUNTY ROAD BRIDGE, PLAINFIELD

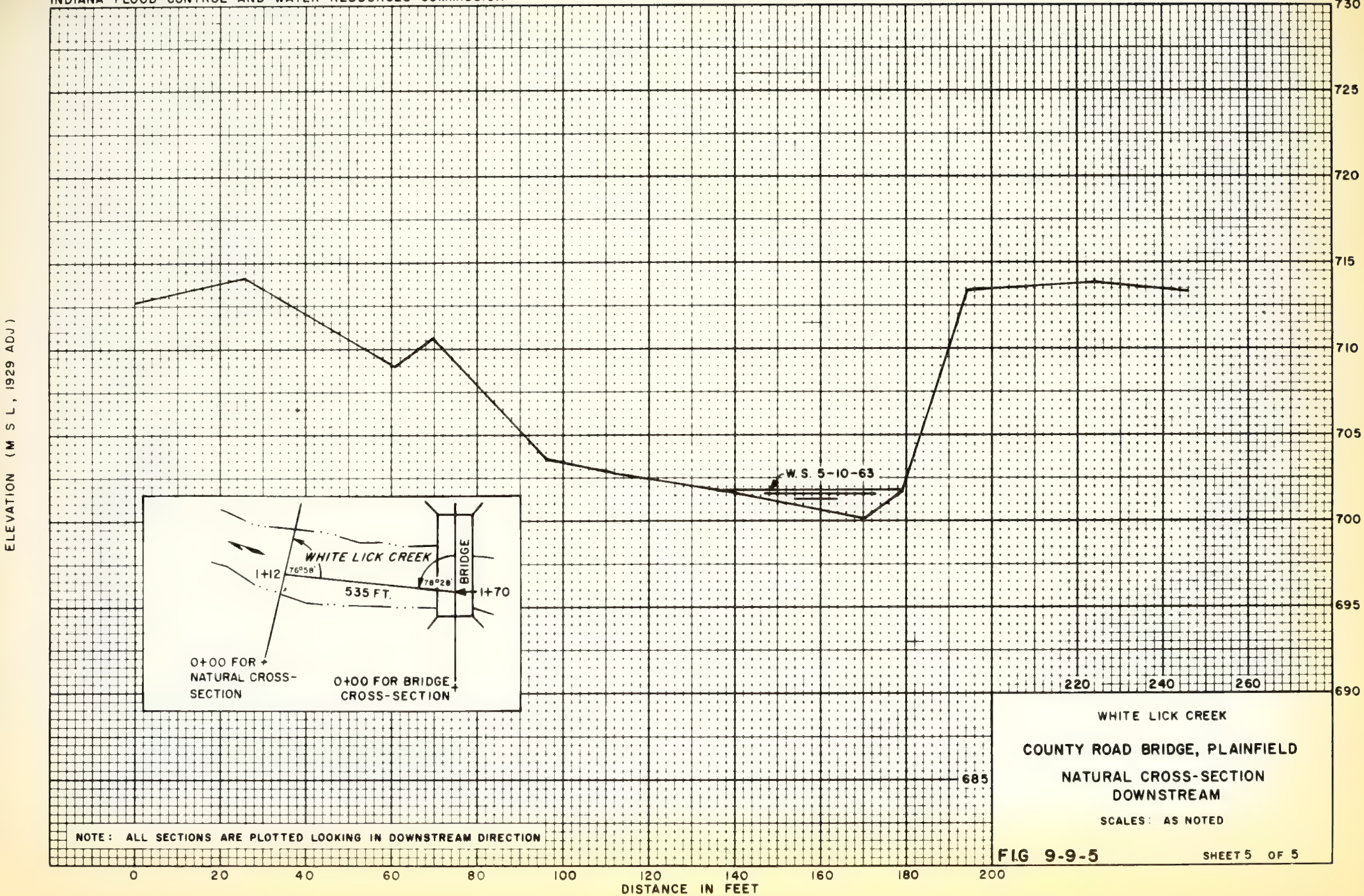
NATURAL CROSS-SECTION
UPSTREAM

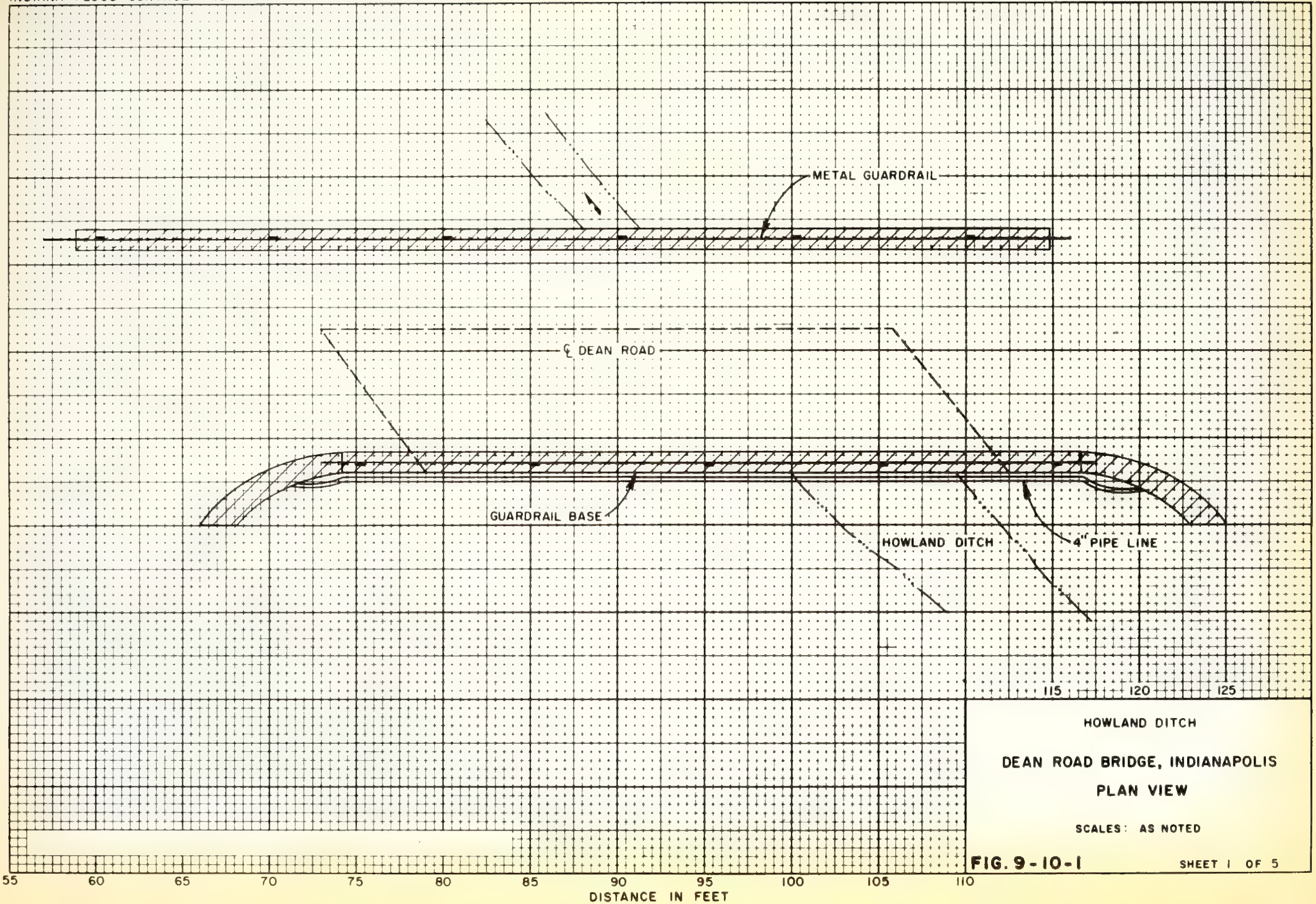
SCALES: AS NOTED

FIG. 9-9-4

SHEET 4 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION





HOWLAND DITCH

DEAN ROAD BRIDGE, INDIANAPOLIS

PLAN VIEW

SCALES: AS NOTED

FIG. 9-10-1

SHEET 1 OF 5

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION

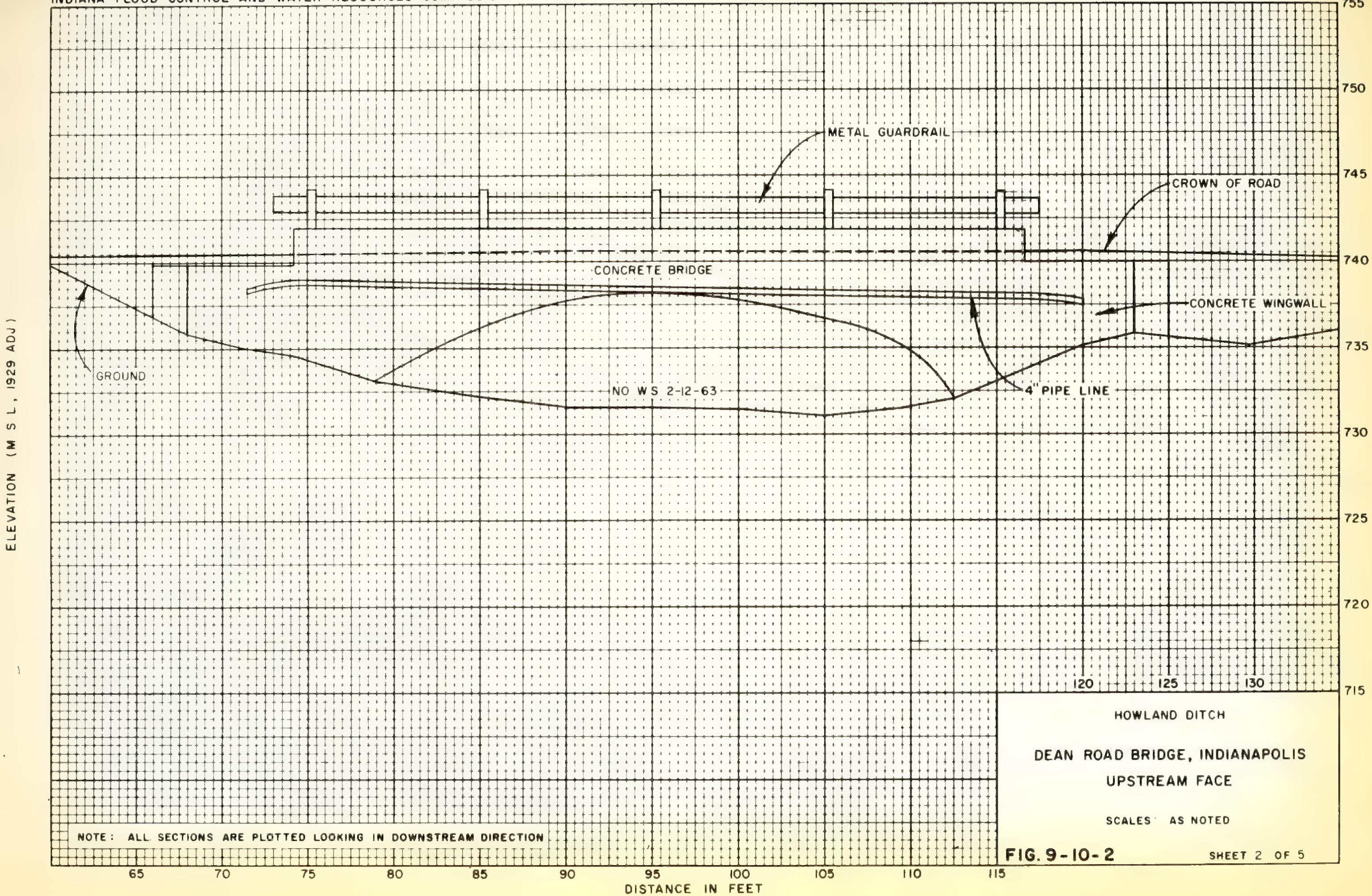


FIG. 9-10-2

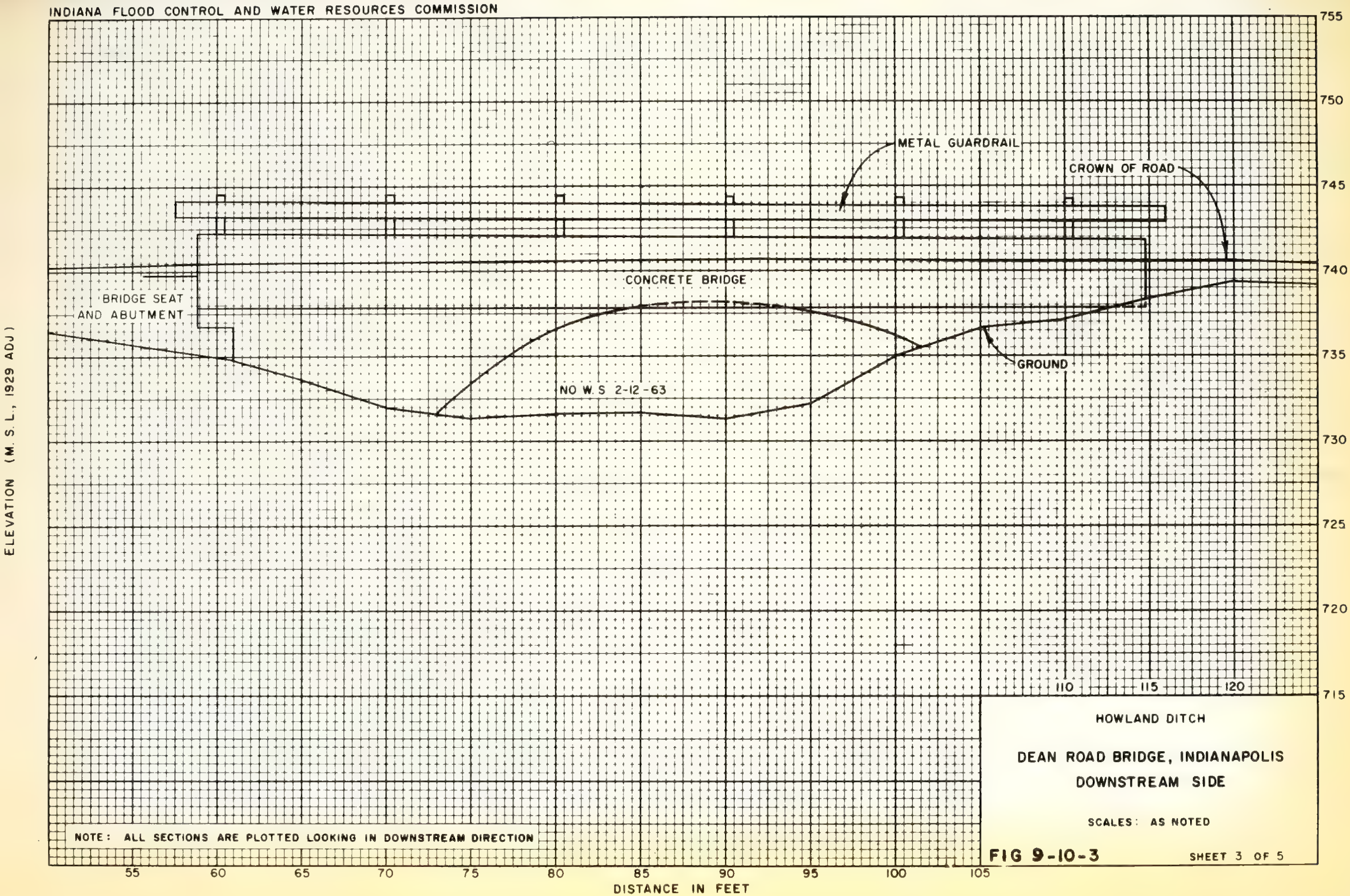
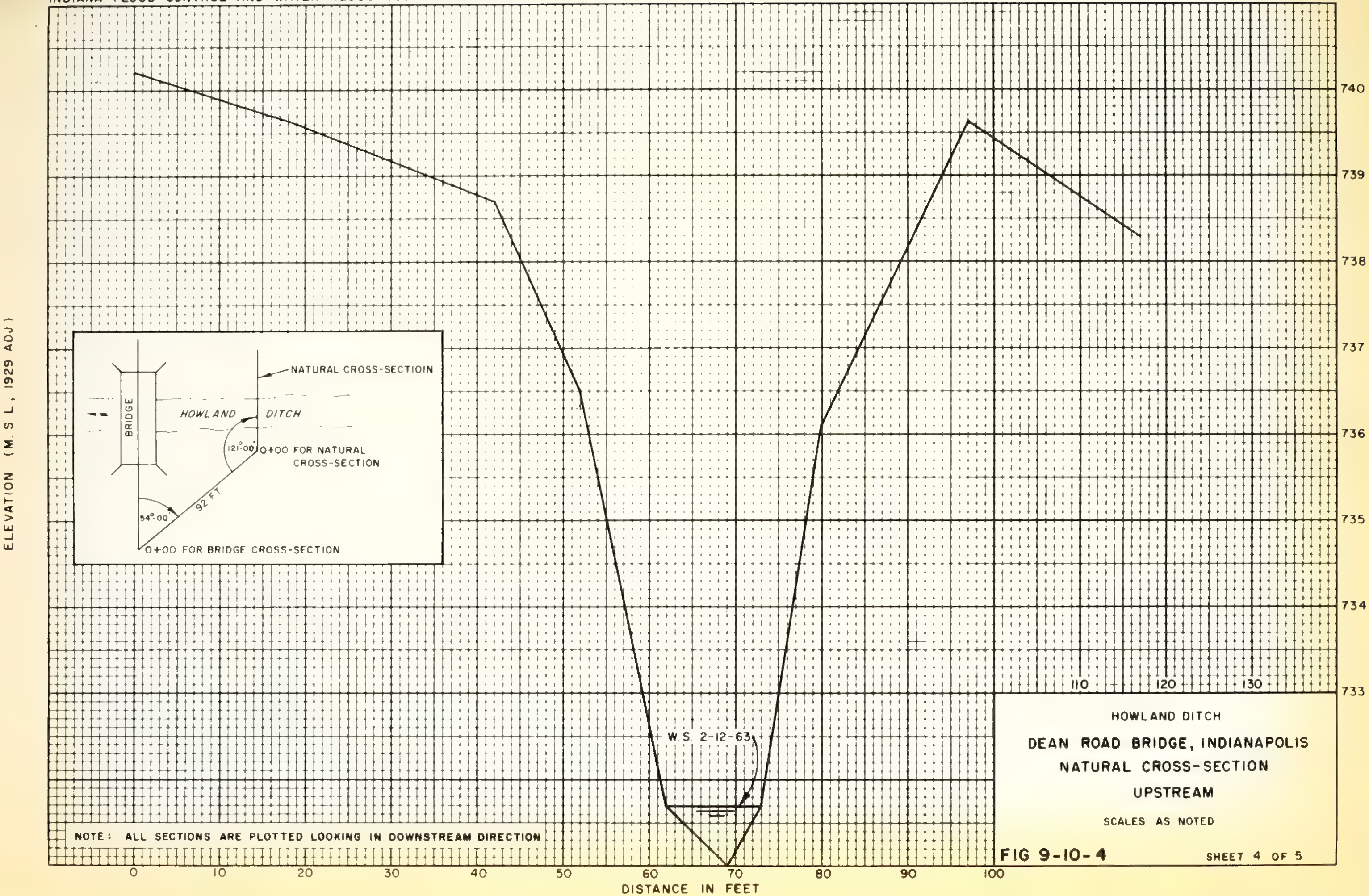

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION
ELEVATION (M. S. L., 1929 ADJ)
755
750
745
740
735
730
725
720
715
METAL GUARDRAIL
CROWN OF ROAD
CONCRETE BRIDGE
BRIDGE SEAT AND ABUTMENT
GROUND
NO W. S 2-12-63
110
115
120
55
60
65
70
75
80
85
90
95
100
105
DISTANCE IN FEET
NOTE: ALL SECTIONS ARE PLOTTED LOOKING IN DOWNSTREAM DIRECTION
HOWLAND DITCH
DEAN ROAD BRIDGE, INDIANAPOLIS
DOWNSTREAM SIDE
SCALES: AS NOTED
SHEET 3 OF 5

FIG 9-10-3

INDIANA FLOOD CONTROL AND WATER RESOURCES COMMISSION



HOWLAND DITCH

DEAN ROAD BRIDGE, INDIANAPOLIS

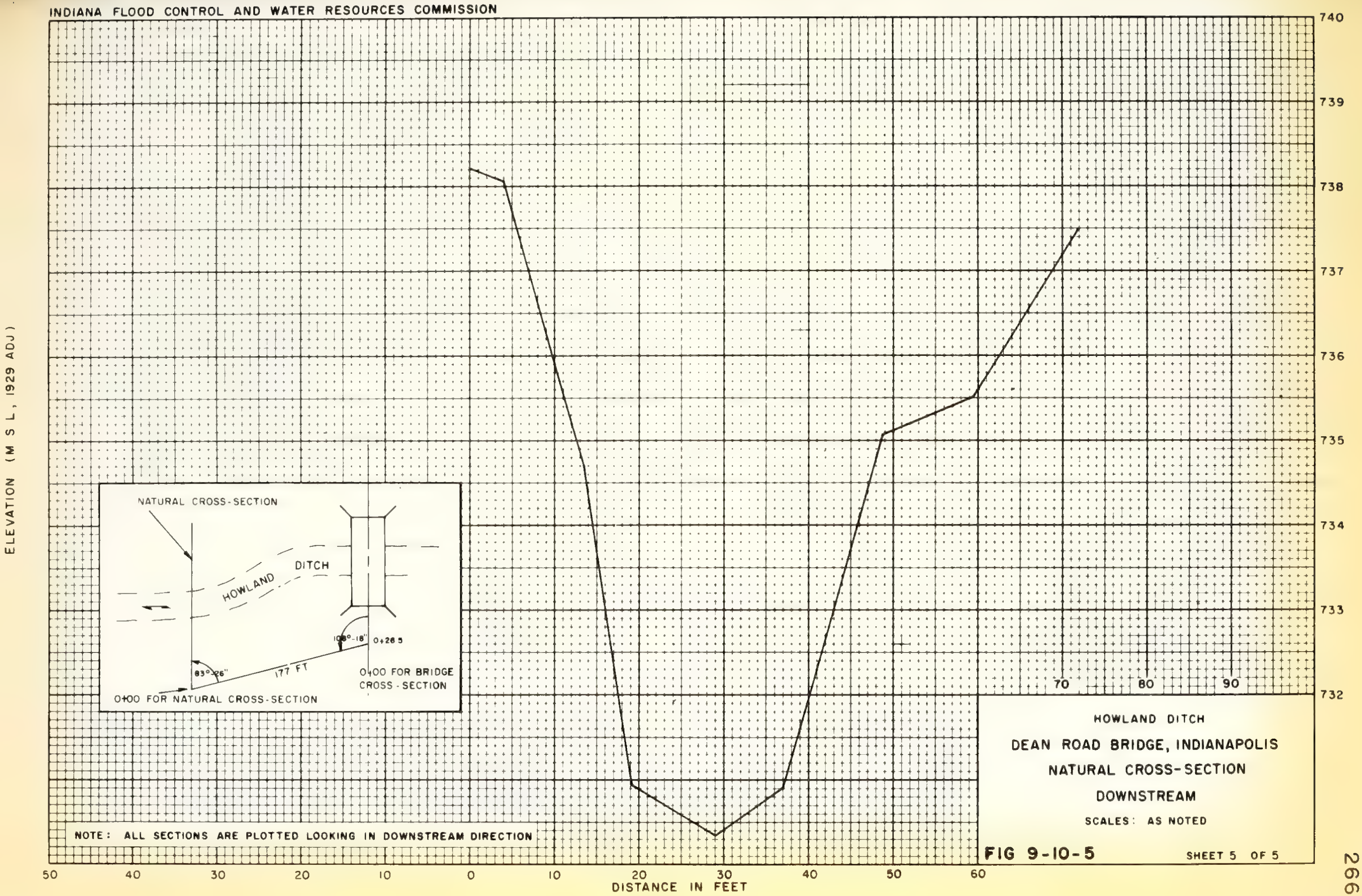
NATURAL CROSS-SECTION

UPSTREAM

SCALES AS NOTED

FIG 9-10-4

SHEET 4 OF 5



HOWLAND DITCH

DEAN ROAD BRIDGE, INDIANAPOLIS

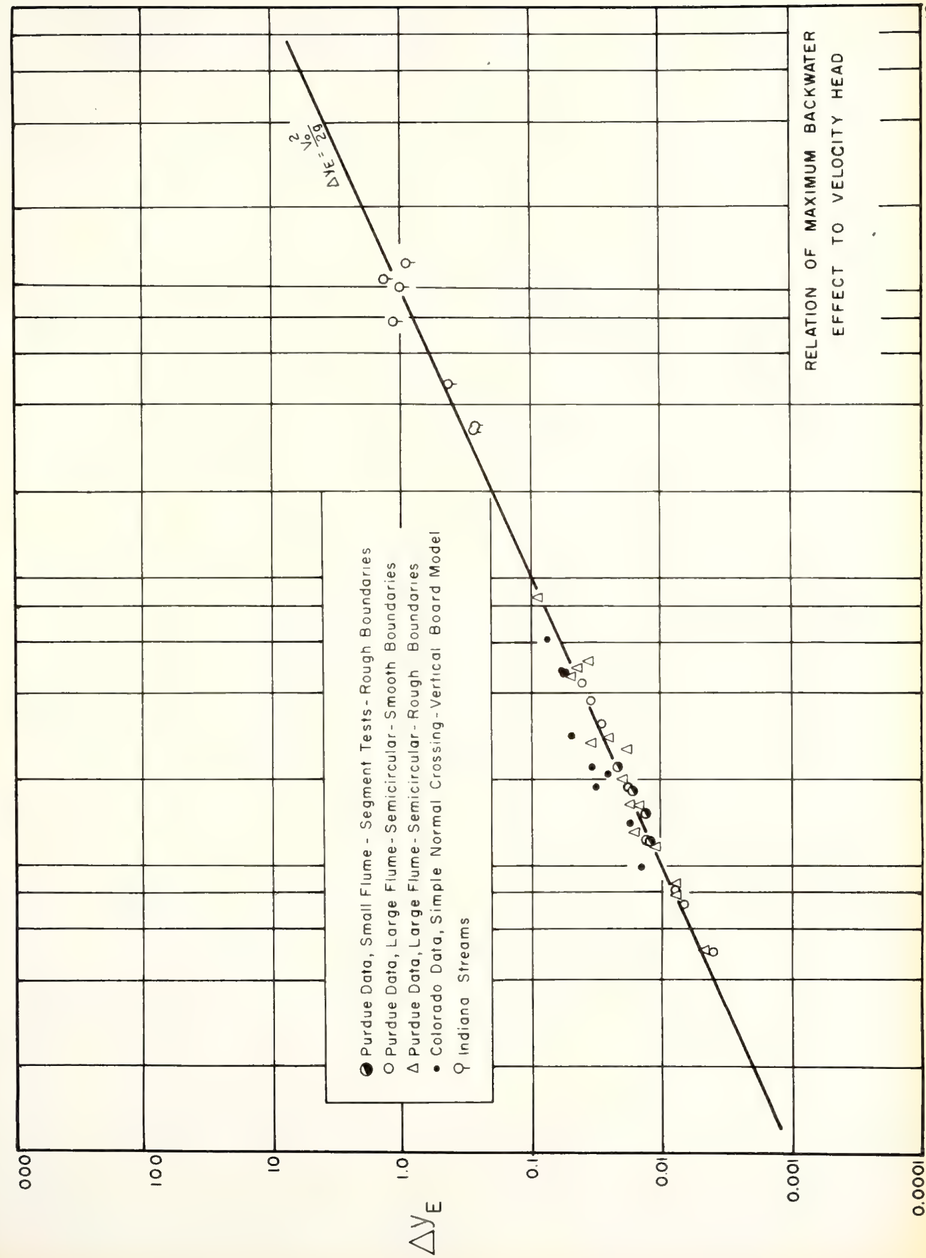
NATURAL CROSS-SECTION

DOWNSTREAM

SCALES: AS NOTED

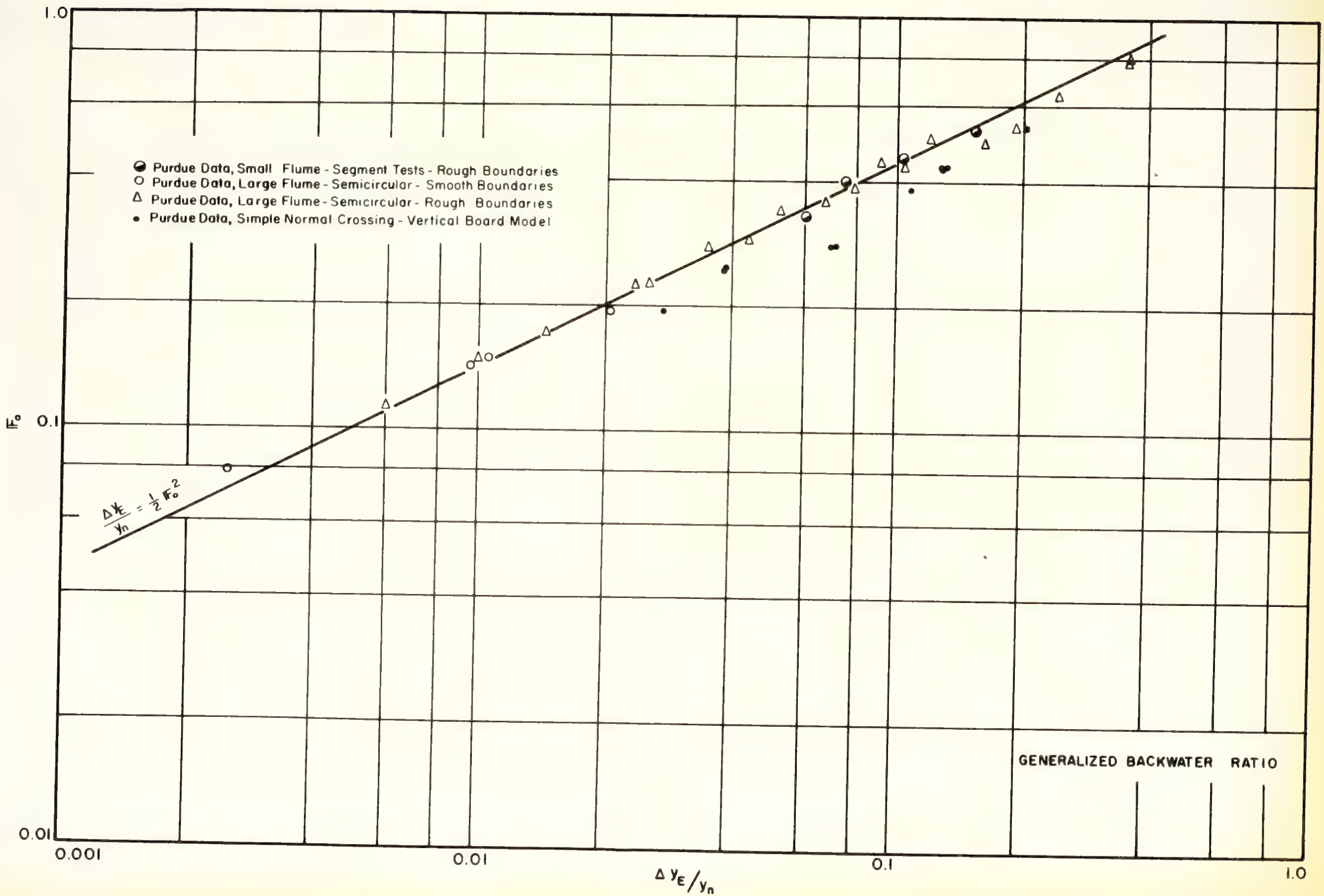
FIG 9-10-5

SHEET 5 OF 5



RELATION OF MAXIMUM BACKWATER EFFECT TO VELOCITY HEAD

FIG. 9-11-1



Purdue Data, Small Flume - Segment Tests - Rough Boundaries
Purdue Data, Large Flume - Semicircular - Smooth Boundaries
Purdue Data, Large Flume - Semicircular - Rough Boundaries
Purdue Data, Simple Normal Crossing - Vertical Board Model
$\frac{\Delta y_E}{y_n} = \frac{1}{2} \mathbb{F}_o^2$
GENERALIZED BACKWATER RATIO
$\mathbb{F}_o$
1.0
0.1
0.01
0.001
0.01
0.1
1.0
$\Delta y_E / y_n$

FIG. 9-11-2

Bridge Number 2A

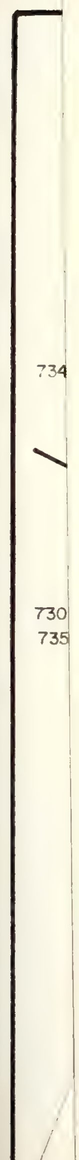
Olney Street and Pogue's Run

Aerial Photographs Numbers 48 (166-167)

Scale: one inch represents fifty feet

July 1963

FIG. 9-1-6


734
730
735

Bridge Number 2C

Pogue's Run to Jefferson

Aerial photographs 48 (170-1)

Scale: one inch represents 50 feet

July 1963

FIG 9-3-6

Bridge Number 8A

South Belmont and Little Buck Creek

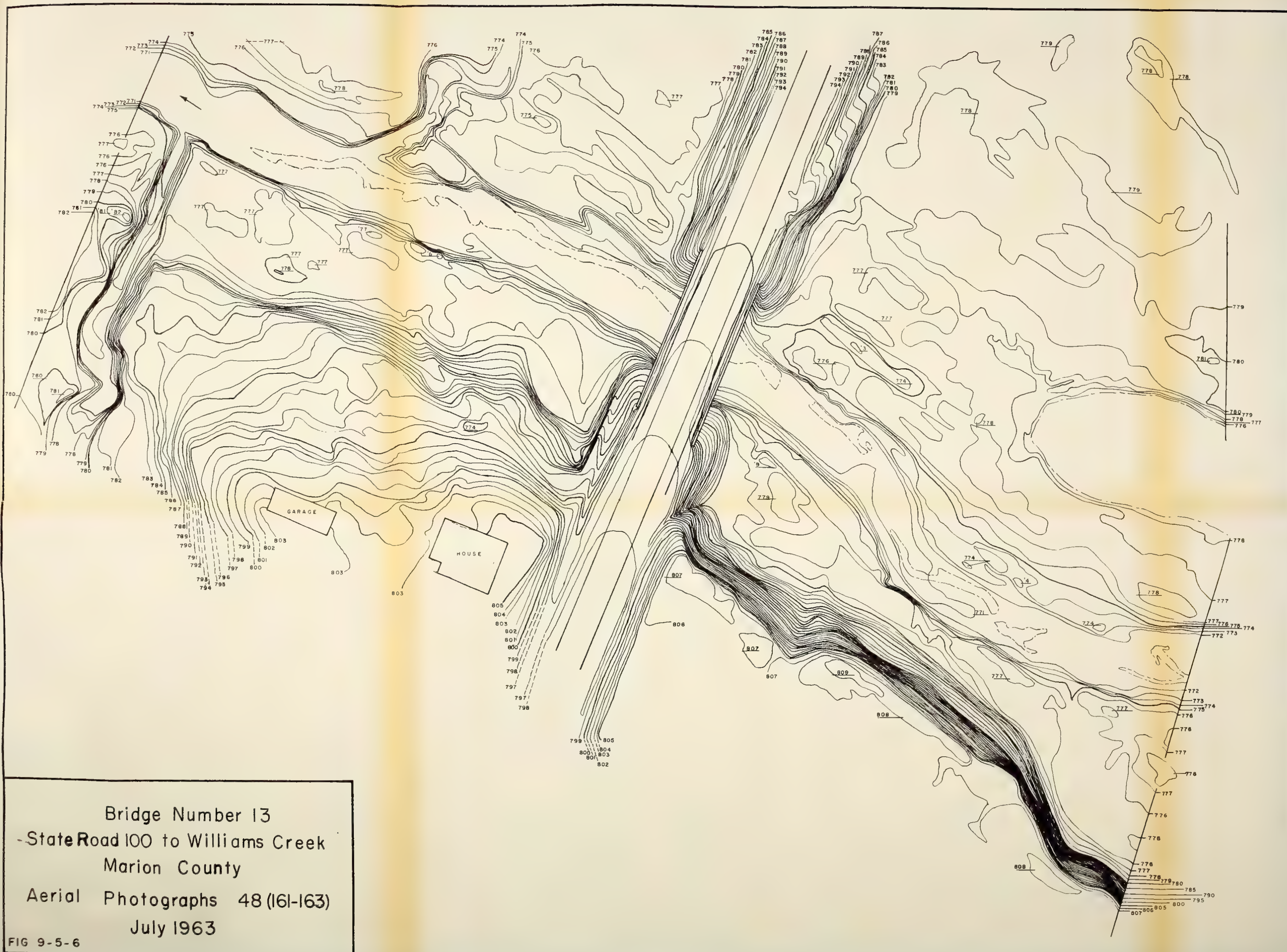
Aerial Photographs 48 (157-8)

Scale: one inch represents 50 feet

July 1963

FIG. 9-4-6

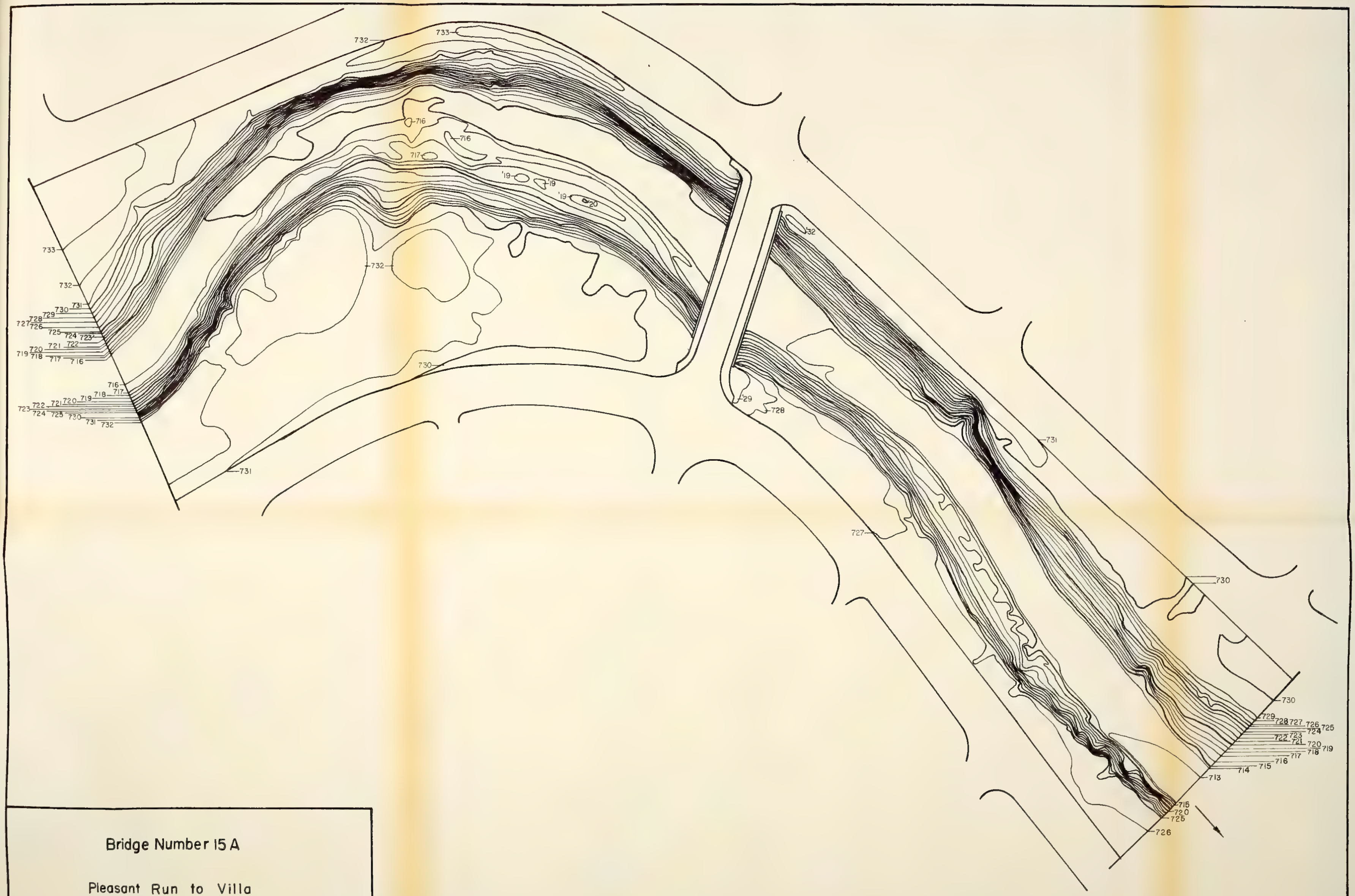

780



Bridge Number 13
-State Road 100 to Williams Creek
Marion County
Aerial Photographs 48 (161-163)
July 1963

FIG 9-5-6


727
719
723



Bridge Number 15 A

Pleasant Run to Villa

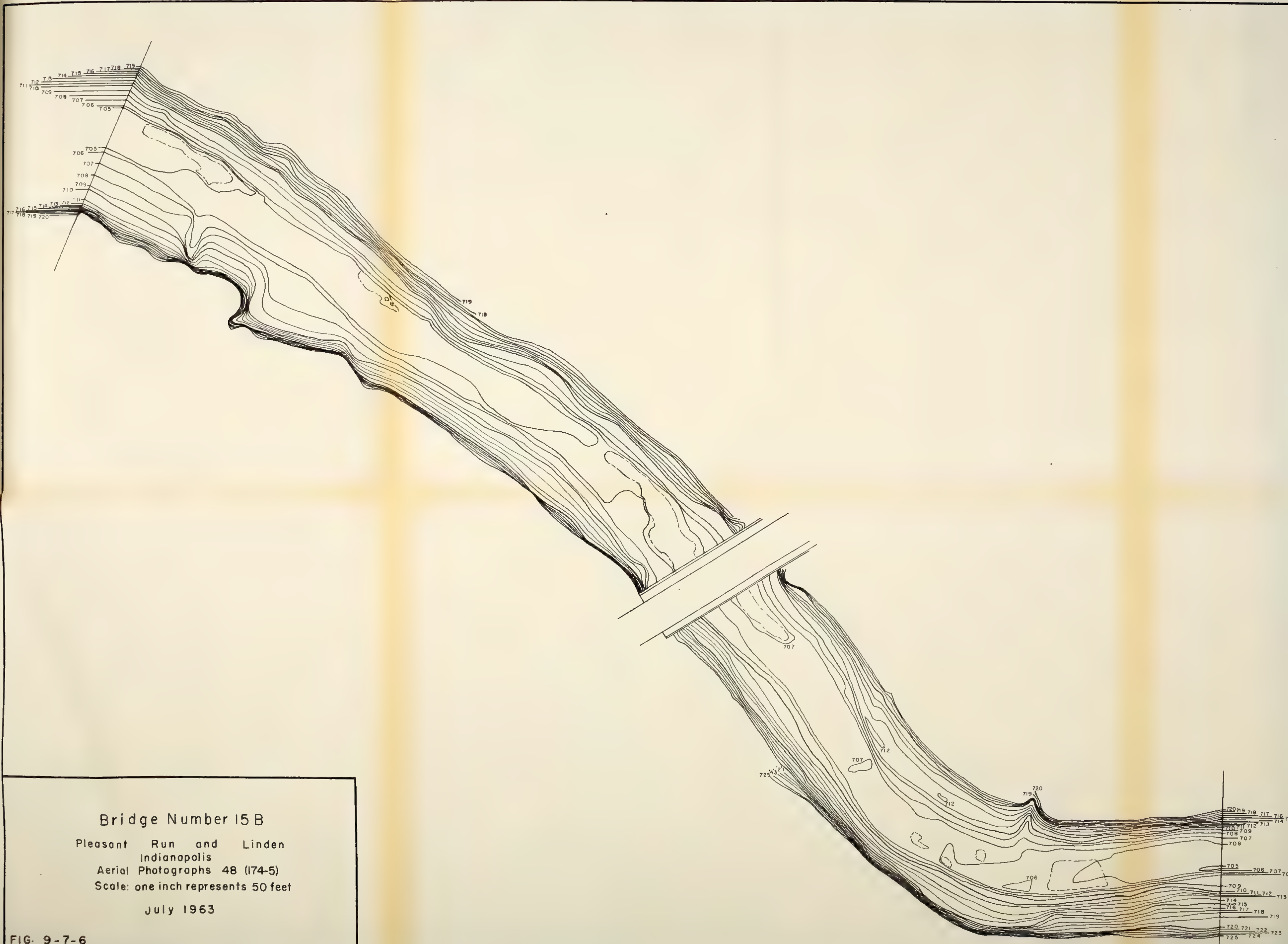
Aerial Photographs 48 (172-3)

Scale: one inch represents 50 feet

July 1963

FIG. 9-6-6


71
717
716
718



Bridge Number 15 B

Pleasant Run and Linden
Indianapolis
Aerial Photographs 48 (174-5)
Scale: one inch represents 50 feet

July 1963

FIG. 9-7-6

Bridge Number 51

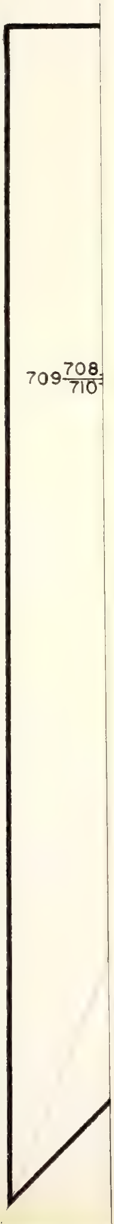
East Jefferson Street and Hurricane Creek

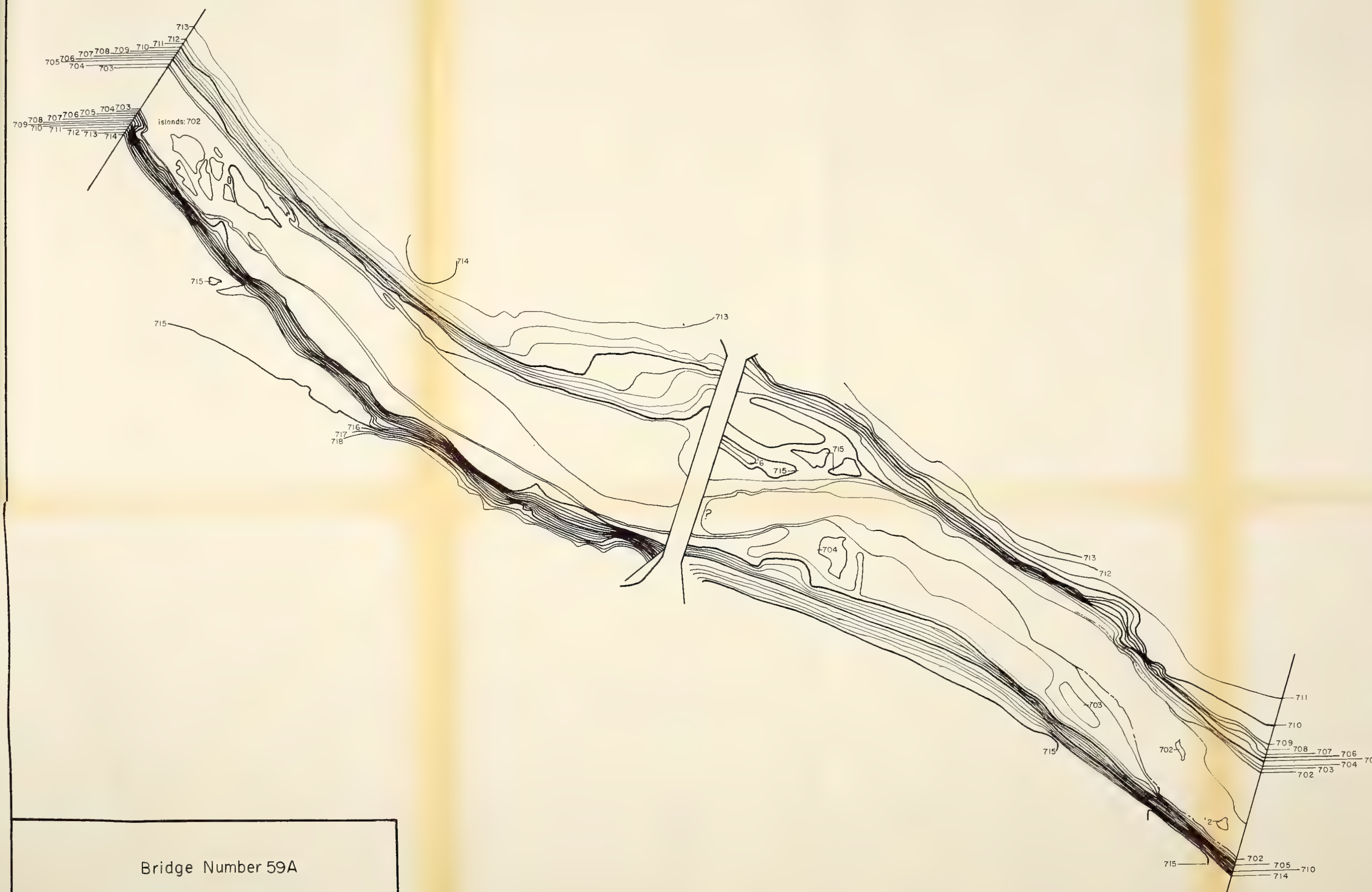
Franklin, Indiana

Aerial Photographs 148 (155-156)

Scale: One inch represents 50 feet

FIG-9-8-6


709
708
710



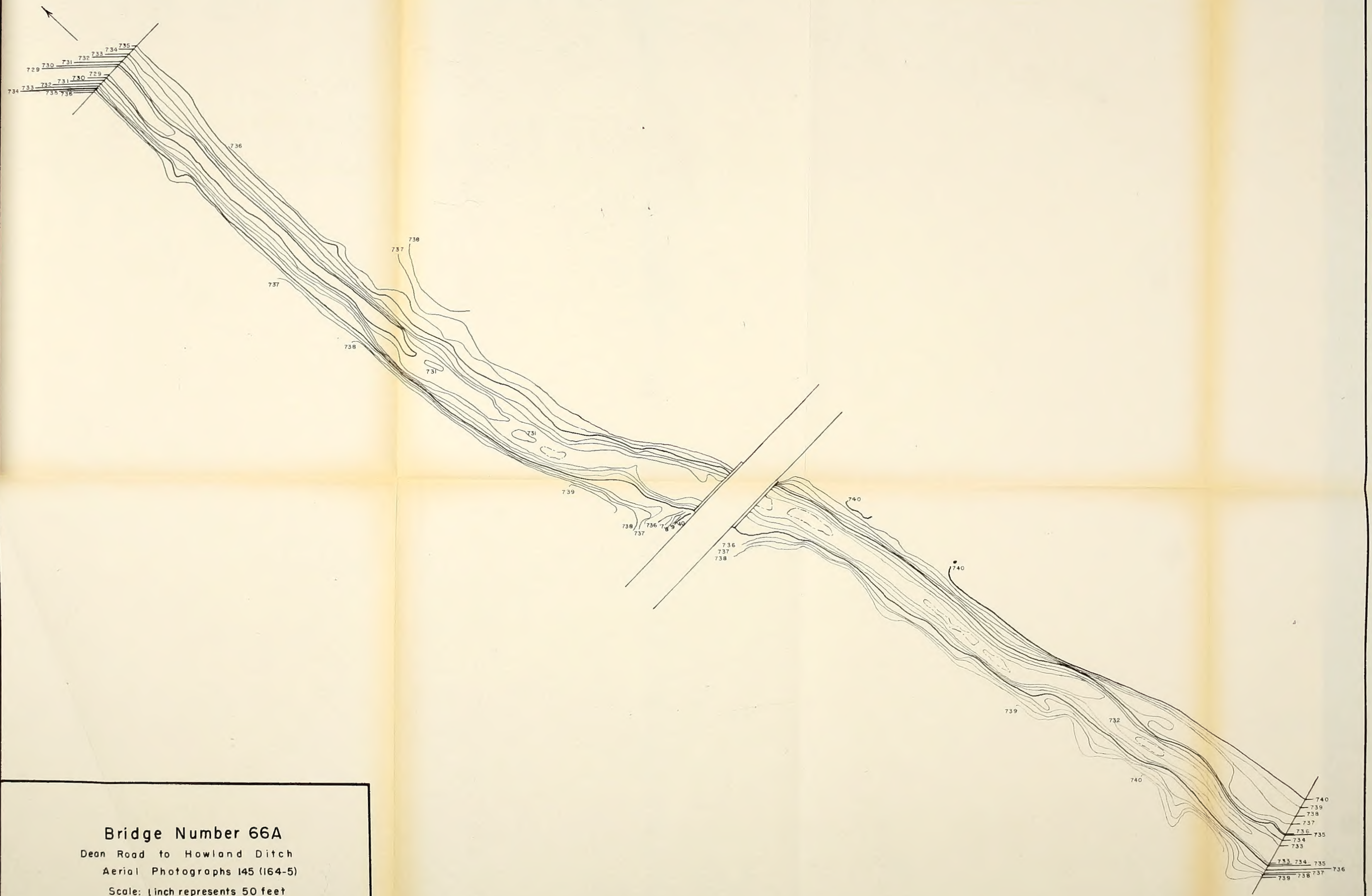
Bridge Number 59A

Plainfield–White Lick Creek and 267

Aerial Photographs 48(159-60)

Scale: one inch represents 50 feet

FIG 9-9-6 July 1963



Bridge Number 66A

Dean Road to Howland Ditch

Aerial Photographs 145 (164-5)

Scale: 1 inch represents 50 feet

July 1963

FIG. 9-10-6